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Municipal Wastewater (Revised)

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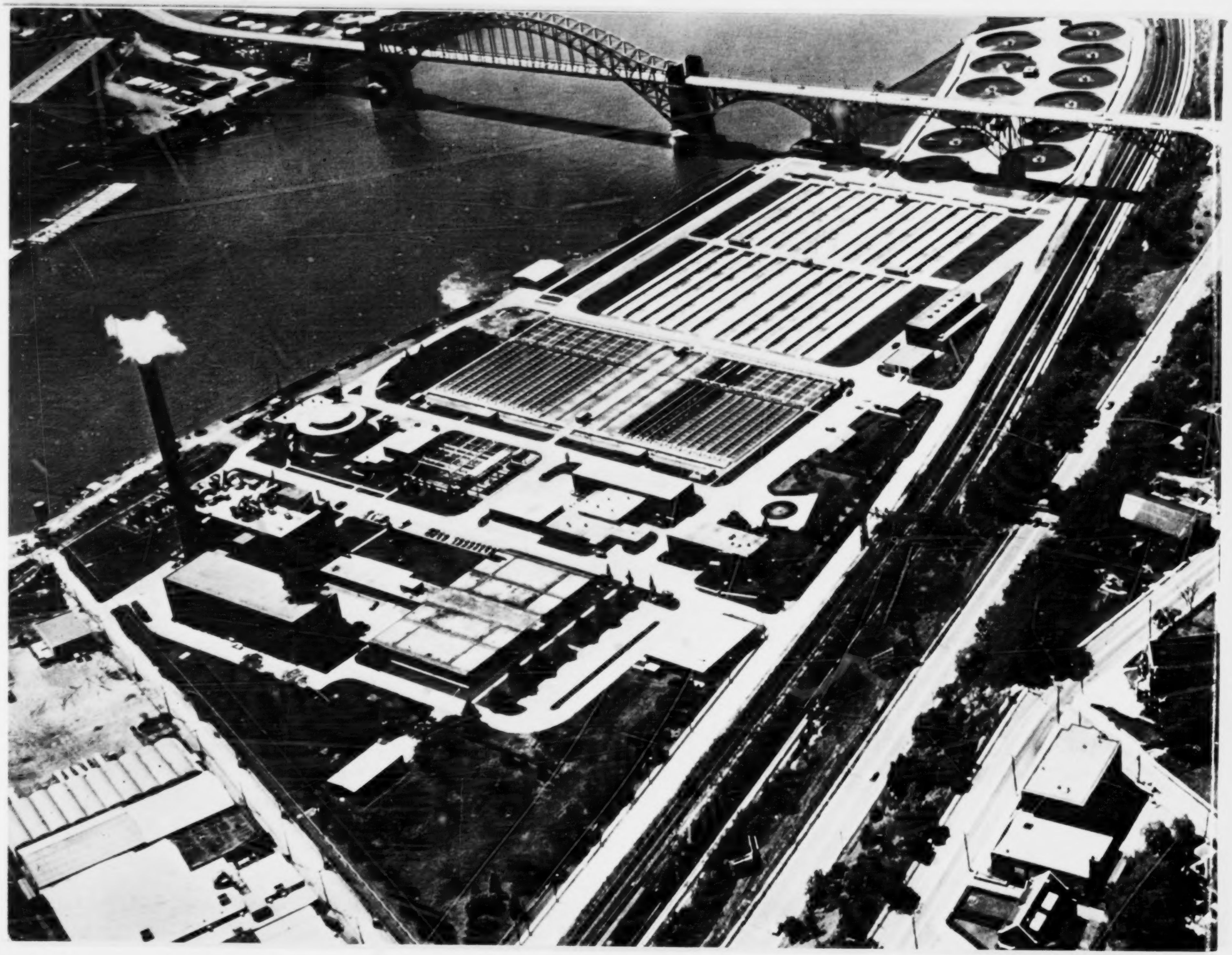


what's in wastewater and why it's of concern

Basically, wastewater is the flow of used water from a community. The name is apt, for wastewater is actually 99.94 percent water by weight. The rest, 0.06 percent, is material dissolved or suspended in the water. The suspended matter is often referred to as "suspended solids" to differentiate it from pollutants in solution.

While "sewage" usually connotes human wastes, the term also includes everything else that makes its way from the home to sewers, coming from various drains, bathtubs, sinks, and washing machines. A generally accepted estimate is that each individual, on a national average, contributes approximately 100 gallons of water per day to a city's sewage flow.

Wastewater also comes from three other sources: commercial, industrial, and storm and ground water. Commercial wastewaters from office buildings and small businesses include both human wastes and water from cleaning or other minor processes. Industrial wastewaters, on the other hand, may consist of large volumes of water used in processing industrial products.

The three basic types of sewage systems that convey wastewater or stormwater are:

Sanitary sewer system—A system that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground, storm, and surface wastes that are not admitted intentionally.

Storm sewer system—A system that carries stormwater and surface water, street wash and other wash waters, or drainage, but excludes domestic wastewater and industrial wastes.

Combined sewer system—A system intended to receive both wastewater and storm or surface water.

Seepage is an undesired source of wastewater flow encountered in separate sewer systems that are in poor repair. Seepage occurs when ground water enters sewer pipes through cracks or loose joints. This problem usually occurs only in older systems, and the improved engineering, materials, and installation methods used now can keep unwanted ground water out of separate sewage systems almost entirely.

The *wastewater components* of major concern are those which will deplete the oxygen resources of the stream or lake to which they are discharged, those which may stimulate undesirable growths of plants or organisms (such as algae) in the receiving water, or those which will have undesirable esthetic effects or adverse health effects on downstream water uses. The pollutants of concern are made up of both organic and inorganic materials.

The *organics* in wastewater are derived from both the animal and plant kingdoms and the activities of man, who may synthesize organic compounds. Organic compounds are normally composed of a combination of carbon, hydrogen, oxygen, and, in some cases, nitrogen. Other important elements, such as sulfur, phosphorus, and iron, may also be present. The principal groups of organic substances found in wastewater are proteins (40-60 percent), carbohydrates (25-50 percent), and fats and oils (10 percent). The use of water in a municipality may add *inorganic* compounds, such as sulfates, chlorides, phosphorus, and heavy metals, which are also of concern from a pollution control standpoint. Some of the organics and inorganics are present in the wastewater as suspended matter (i.e., suspended solids) while the rest are in solution. Most of the suspended solids can be simply removed by allowing the wastewater to stand quietly to permit the solids to settle. The soluble organic and inorganic pollutants are more difficult to remove.

Of the organics found in wastewater, a substantial portion consists of *biodegradable* materials—those which serve as food sources for bacteria and other micro-organisms. These biodegradable substances include such compounds as sugars, alcohols, and many other compounds that may find their way into sewers. The biological breakdown of these materials consumes oxygen. The amount of oxygen required to stabilize the biodegradable organics is measured by the biochemical oxygen demand

(BOD) test. The higher the BOD, the more oxygen will be demanded from the water to break down the organics. This parameter is the most widely used measure of organic pollution applied to wastewaters. It is used in sizing treatment facilities and in predicting the effects of treated wastewater discharges on receiving waters. If the oxygen demand of the treated wastewater exceeds the oxygen resources of the receiving water, then the oxygen will be completely depleted and the stream or lake will become septic near the wastewater discharge point.

Because fish and many beneficial aquatic plants require oxygen to survive, the removal of BOD becomes a major goal of all wastewater treatment plants. Many years ago our population and industry was so sparse and scattered that we could rely on Nature's treatment in streams and lakes to remove BOD without overtaxing the oxygen resources of our waters. When our population and industrial activities increased and the construction of treatment facilities failed to keep pace, many of our streams and lakes suffered a noticeable loss of fish life. For example, before recent cleanup measures were completed, the runs of salmon up Oregon's Willamette River came to a virtual halt as a result of lack of oxygen in the Portland harbor. Wastewater treatment plants have now been placed in operation in the Willamette Basin, and these plants are so effective in removing BOD that the salmon runs have been restored—an excellent example of the positive results that can be achieved by the use of available treatment processes.

Some of the organics in wastewater are not biologically degradable and, thus, are not part of the BOD. Some of these *nondegradable organics*, such as pesticides, can have adverse long-term effects and can contribute to taste, odor, and color problems in downstream water supplies. The chemical oxygen demand (COD) test is used to measure the quantities of these materials present. The COD value also reflects biologically degradable materials; therefore, the COD is higher than the BOD because more compounds can be oxidized chemically than biologically. Some of the COD-causing materials are organics that are very resistant to breakdown in the environment; they are of particular concern where water is used for a municipal water supply downstream.

Fortunately, there are treatment techniques available for removing wastewater COD as well as BOD. These techniques are discussed later in this publication.

Wastewater contains *bacteria and viruses* that can transmit diseases. This consideration can be especially critical if the receiving water is used for recreation near the point of wastewater discharge. As early as 1854, it was established that cholera was transmitted by sewage-contaminated drinking water. A hepatitis epidemic in Delhi, India, in 1955, was also traced to contamination of a water supply by sewage. An amoebic dysentery outbreak in Chicago in 1933 from sewage-contaminated water caused 23 deaths. Thus, another important wastewater treatment concern is often the removal of as many pathogenic bacteria and viruses as possible before discharge of the wastewater. Because bacteria and viruses are of minute size, they can be enmeshed in suspended solids in the wastewater. The suspended solids can act as a shield to protect bacteria and viruses from contact with added disinfecting agents, hampering the disinfection process. Thus, removal of suspended solids is important to insure good disinfection

as well as to provide removal of some of the insoluble organic and inorganic pollutants.

Wastewater also contains two elements—phosphorus and nitrogen—that can stimulate undesirable growths of algae in lakes and streams. These algal growths can cause thick, green, scumlike mats that interfere with boating and recreation. They also may cause unpleasant tastes and odors in water supplies and operating problems in downstream water treatment plants, and may exert a significant oxygen demand after the algae die. Where receiving waters are particularly sensitive to stimulation of algae, removal of phosphorus and nitrogen is of concern.

Heavy metal pollutants recently have received a great deal of emphasis as a result of the concern over mercury discharges. Many heavy metals (such as mercury, silver, chromium, lead, zinc, and cadmium) may find their way into municipal wastewaters from commercial or industrial sources—or even from a hobbyist's darkroom! The toxic effects of those metals can interfere with biological waste treatment processes. If these metals enter the receiving water in sufficiently high concentrations, they can cause fish kills and create a problem in downstream water supplies. In smaller quantities they may not cause immediate fish kills, but can enter the aquatic food chain where they can accumulate and cause long-term problems.

During use of water in a municipality, the mineral quality of the water is altered. Inorganic salts containing calcium, magnesium, sodium, potassium, chlorides, sulfates, and phosphates are among the pollutants added. These pollutants are normally referred to as total dissolved solids (TDS). Normal water treatment practices at downstream locations do not remove these solids. As a result, the dissolved-solids content increases as a supply source such as a major river passes through several users in series. Excessive dissolved-solids concentrations can result in unpalatable taste and some physiological problems. A high dissolved-solids concentration can also adversely affect irrigation use, industrial use, or stock and wildlife watering. Calcium and magnesium contribute to downstream water hardness. Control of the TDS can be of concern in arid areas where little dilution is available and where reuse of wastewater may be desired (as in southern California).

As noted earlier, municipal wastewater is usually 99.94 percent water; thus the concentrations of the pollutants discussed are very dilute. These concentrations are usually expressed as milligrams of pollutant per liter of water (mg/l). One mg/l of a pollutant is equivalent to 1 part of the pollutant (by weight) in 1 million parts of water—or, as expressed in another often-used term, 1 part per million (ppm). One mg/l or 1 ppm, to put the terms in perspective, is equivalent to 1 minute of time in 1.9 years or 1 inch in 16 miles. These statistics emphasize that wastewater treatment processes designed to remove a few milligrams per liter of a pollutant are similar to sifting a haystack to remove the needle. However, the balance in Nature for survival or death of fish depends on the presence or absence of only 2-3 mg/l of oxygen in the stream or lake, and undesirable growths of algae can be stimulated by a few tenths of a milligram of phosphorus and nitrogen per liter. Typical concentrations of pollutants in raw, untreated, municipal wastewaters are as follows: BOD = 150-250 mg/l, COD = 300-400 mg/l, suspended solids = 150-250 mg/l, phosphorus = 5-10 mg/l, nitrogen = 15-25 mg/l, and TDS = 400-500 mg/l.

what general treatment approaches are available?

The alternatives for municipal wastewater treatment fall into three major categories:

- Primary treatment
- Secondary treatment
- Advanced wastewater treatment

The major goal of *primary treatment* is to remove from wastewater those pollutants which will either settle (such as the heavier suspended solids) or float (such as grease). Primary treatment will typically remove about 60 percent of the raw sewage suspended solids and 35 percent of the BOD. Soluble pollutants are not removed. At one time, this was the degree of treatment used by many cities. Now Federal law requires that municipalities provide the higher degree of treatment provided by secondary treatment. Although primary treatment alone is no longer acceptable, it is still frequently used as the first treatment step in a secondary treatment system. Thus, past investments in primary treatment facilities provide useful treatment functions when treatment is upgraded to the secondary level.

The major goal of *secondary treatment* is to remove the soluble BOD that escapes the primary process and to provide added removal of suspended solids. These removals are typically achieved by using biological processes, providing the same biological reactions that would occur in the receiving water if it had adequate capacity to assimilate the wastewater discharges. The secondary treatment processes are designed to speed up these natural processes so that the breakdown of the degradable organic pollutants can be achieved in relatively short time periods in treatment units that relieve our streams and lakes of the purification burden. Although secondary treatment may remove more than 85 percent of the BOD and suspended solids, it does not remove significant amounts of nitrogen, phosphorus, COD, or heavy metals, nor does it completely remove pathogenic bacteria and viruses. These latter pollutants may require further removal where receiving waters are especially sensitive.

In cases where secondary levels of treatment are not adequate, new treatment processes are applied to the secondary effluent to provide *advanced wastewater treatment*, or further removal of the pollutants. Some of these processes may involve chemical treatment and filtration of the wastewater—much like adding a typical water treatment plant to the tail end of a secondary plant—or they may involve applying the secondary effluent to the land in carefully designed irrigation systems where the pollutants are removed by a soil-crop system. Some of these new processes can remove as much as 99 percent of the BOD and phosphorus, all suspended solids and bacteria, and 95 percent of the nitrogen, and can produce a sparkling clear, odorless effluent indistinguishable in appearance from a high-quality drinking water. Although these processes and land treatment systems are often applied to secondary effluent for advanced treatment, they have also been used in place of conventional secondary treatment processes.

Most of the impurities removed from the wastewater do not simply vanish, although some organics are broken down into harmless carbon dioxide and water. Instead, most impurities are removed from the wastewater as solids, leaving a residue called "sludge." Because most of the impurities removed from the wastewater are present in the sludge, sludge handling and disposal must be carefully carried out to achieve satisfactory pollution control. Untreated sludge still consists largely of water—as much as 98-99 percent. Many treatment plants use a digestion process followed by a drying process for sludge treatment. Sludge digestion takes place in heated tanks where the material can decompose naturally and the odors can be controlled. Because digested sludge contains about 95 percent water, the next step in treatment must be the removal of as much of the water as possible. Many small plants dry their sludge on open drying beds made up of sand and gravel. The sludge is spread on the bed and allowed to dry. After a week or two of drying, the residue is removed and used as a soil conditioner or landfill. In most areas, the available land around treatment plant sites is at a premium; as a result, other methods of sludge treatment are finding increased use. In some cases, the sludge is dewatered by mechanical devices and then burned in incinerators. These incinerators are carefully designed and equipped with air pollution control equipment so that the sludge-handling process does not add to the pollution of the atmosphere. In other cases, the sludge may be used as a soil conditioner. The city of Milwaukee, Wisconsin, has dewatered and dried its sewage sludges for years. The dried material is bagged and sold under the name "Milorganite" as a soil conditioner. Sludge is also used in a semiliquid form by cities such as Chicago, Illinois, for reclaiming large land areas. Chicago's project will eventually restore 10,000 acres of unproductive strip-mined land for use as a productive agricultural area.

The rest of this publication will describe the alternatives for wastewater treatment and sludge handling in detail.

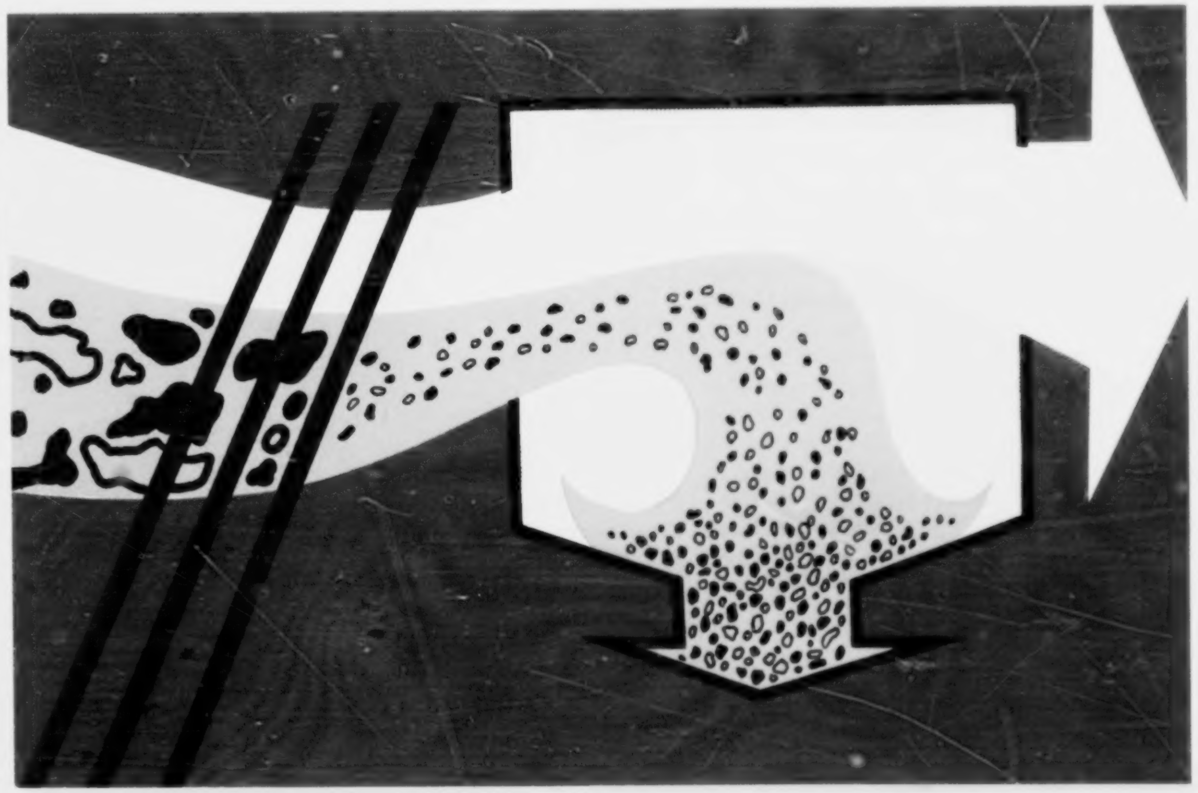
primary treatment

Primary treatment removes from the wastewater those pollutants which will either settle out or float. As wastewater enters a plant for primary treatment, it flows through a screen. The screen removes large floating objects, such as rags and sticks, that may clog pumps and small pipes. The screens typically are made of parallel steel or iron bars with openings of about half an inch.

Screens are generally placed in a chamber or channel in an inclined position to the flow of the sewage to making cleaning easier. The debris caught on the upstream surface of the screen can be raked off manually or mechanically. The debris removed from the screen is usually buried in a landfill.

Some plants use a device known as a comminutor, which combines the functions of a screen and a grinder. This device catches and then cuts or shreds the heavy solid material. The pulverized matter remains in the wastewater flow to be removed later in a settling tank.

After the wastewater has been screened, it passes into a grit chamber, where sand, grit, cinders, and small stones are allowed to settle to the bottom. A grit chamber is highly important for cities with combined sewer systems, because it will remove the grit or gravel that washes off streets or land during a storm and ends up at treatment plants.

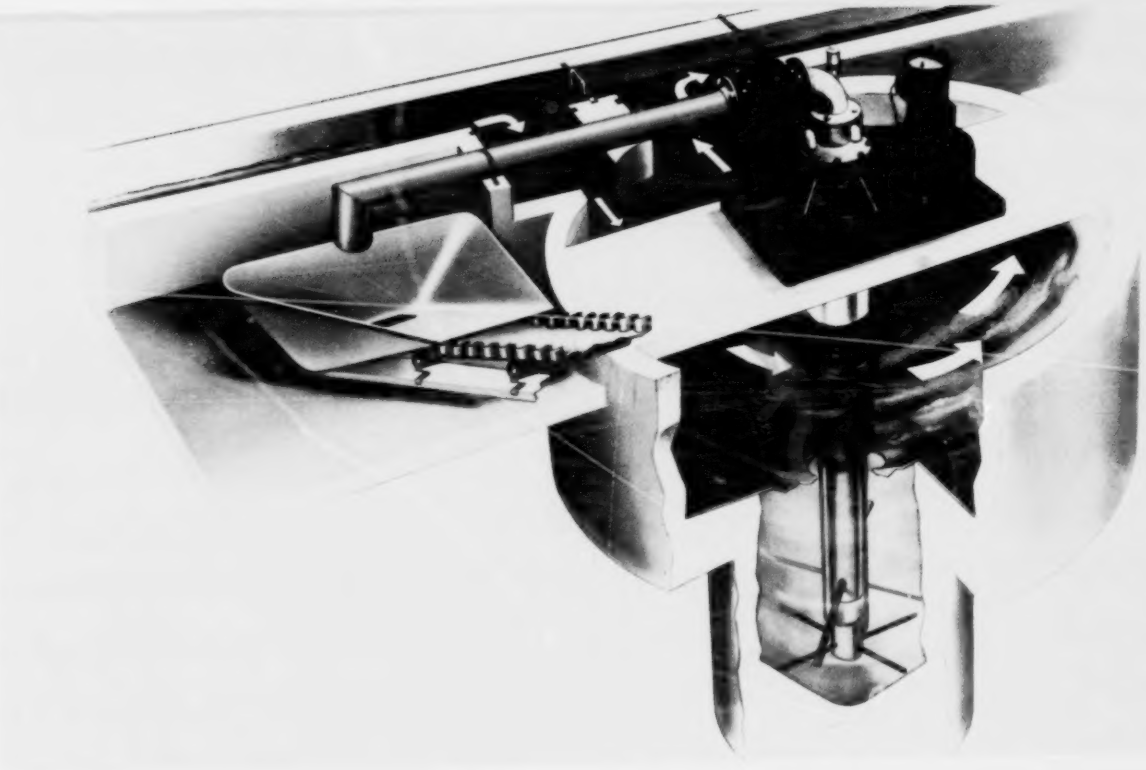


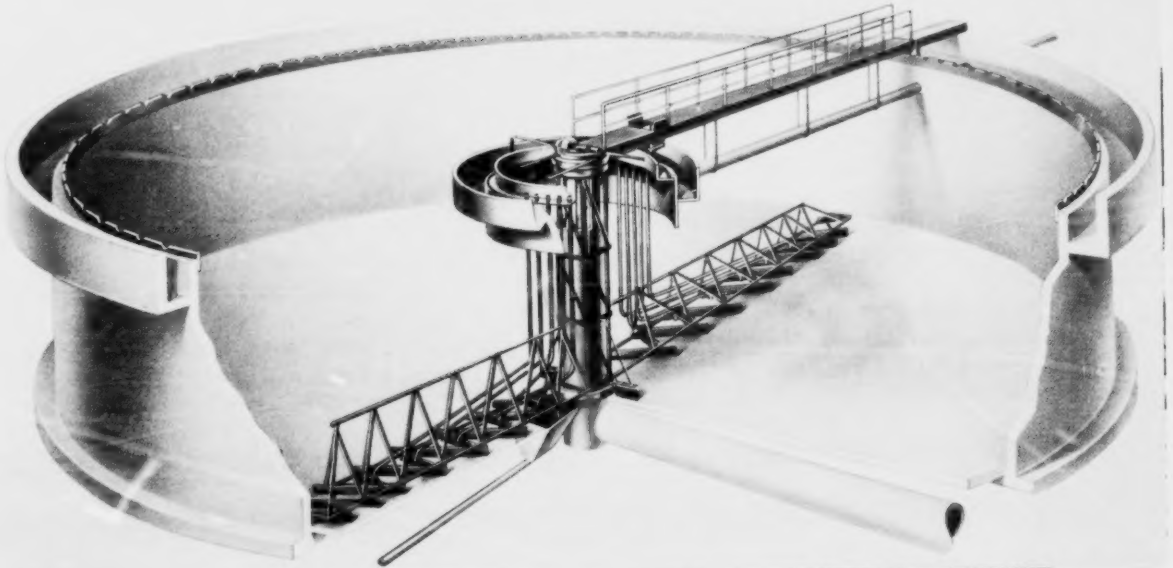
The grit or gravel removed by the grit chamber is usually taken from the tank, washed so that it is clean, and disposed of by landfilling near the treatment plant.

With the screening completed and the grit removed, the wastewater still contains suspended solids, some of which can be removed from the sewage by treatment in a sedimentation tank. These tanks may be round or rectangular, are usually 10-12 feet deep, and hold the wastewater for periods of 2-3 hours. Wastewater flows very slowly through them, so that the suspended solids gradually sink to the bottom. This mass of settled solids is called raw primary sludge. The sludge is removed from the sedimentation tank by mechanical scrapers and pumps. Floating materials, such as grease and oil, rise to the surface of the sedimentation tank, where they are collected by a surface-skimming system and removed from the tank for further processing, usually in a sludge digester.

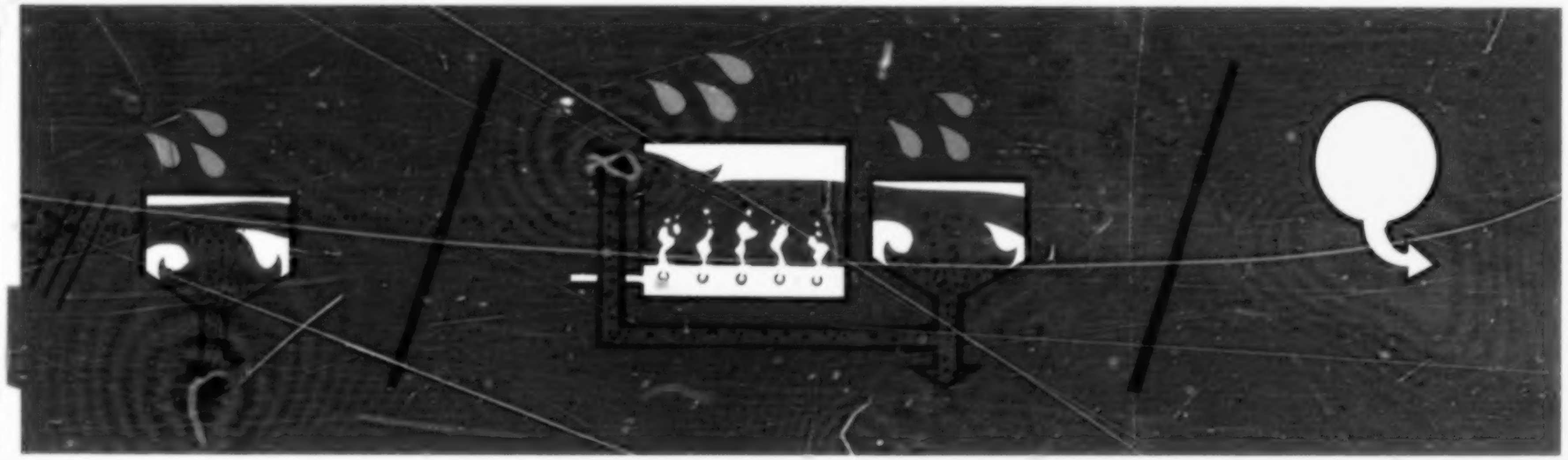
Energy Requirements. Primary treatment (consisting of screening, comminution, aerated grit removal and sedimentation) has a considerably lower power requirement than either secondary treatment or advanced wastewater treatment. The power consumption per million gallons treated is 71 kilowatt-hours (kwh) for a 1-million gallons per day (mgd) plant and 17 kwh for a 10-mgd plant. To put the power consumption of this process and others in perspective, a consumption of 1,000 kwh per million gallons corresponds to a per family electrical use of a 15-watt light bulb burning continuously.

Costs. The costs of wastewater treatment are typically expressed in terms of cost per volume of wastewater treated, often as cents per 1,000 gallons. Costs are composed of both the construction (capital) costs and the daily costs to operate and maintain the facility. Capital costs are expressed as the annual costs, including interest, to amortize the total investment in the treatment facility. The costs are typically amortized over a 20-year period. By adding together the annual capital costs and the operation and maintenance costs, a total annual cost is obtained. The cost per 1,000 gallons is then determined by dividing the total annual cost by the total wastewater volume treated during the year. Because the costs per 1,000 gallons will vary with the portion of the available capacity actually used, comparisons are usually made based on the costs experienced when the facility operates at its full design capacity. Costs also vary with plant size; economics of scale are realized in larger plants. The local capital costs can be reduced substantially (by a factor of 4) if federal construction grants are received. Cost estimates in this publication will be based on the 1-10 mgd capacity range, which encompasses most municipal plants (10,000-100,000 population served), and on *total* capital costs (no grant funding). Costs per 1,000 gallons will be higher in smaller plants outside this range and lower in larger plants. Based on September 1977 price levels, the cost of primary treatment (including comminution, aerated grit removal and sedimentation) will be about 15 cents per 1,000 gallons at 10 mgd (based on amortization of capital costs over 20 years at 7 percent interest). At a sewage flow of about 350 gallons per day from an average residence, these treatment costs are equivalent to $1.60 per month per home at 1 mgd and $0.55 per month at 10 mgd.





secondary treatment



The major purpose of secondary treatment is to remove the soluble BOD that escapes primary treatment and to provide further removal of suspended solids. A minimum of secondary treatment is now required for municipalities. In most cases, secondary processes are biological in nature, designed to provide the proper environment for the biological breakdown of soluble organic materials. A great variety of biological micro-organisms come into play—bacteria, protozoa, rotifers, fungi, algae, and so forth. All biological processes depend on bringing these organisms into contact with the impurities in the wastewater so that they can use these impurities as food. The organisms convert the biodegradable organics into carbon dioxide, water, and—just as when a person consumes food—more cell material. This biological breakdown of organic material requires oxygen. The basic ingredients needed for secondary biological treatment are the availability of many micro-organisms, good contact between these organisms and the organic material, the availability of oxygen, and the maintenance of other favorable environmental conditions (for example, favorable temperature and sufficient time for the organisms to work). A variety of approaches have been used in the past to meet these basic needs. The most common approaches are called

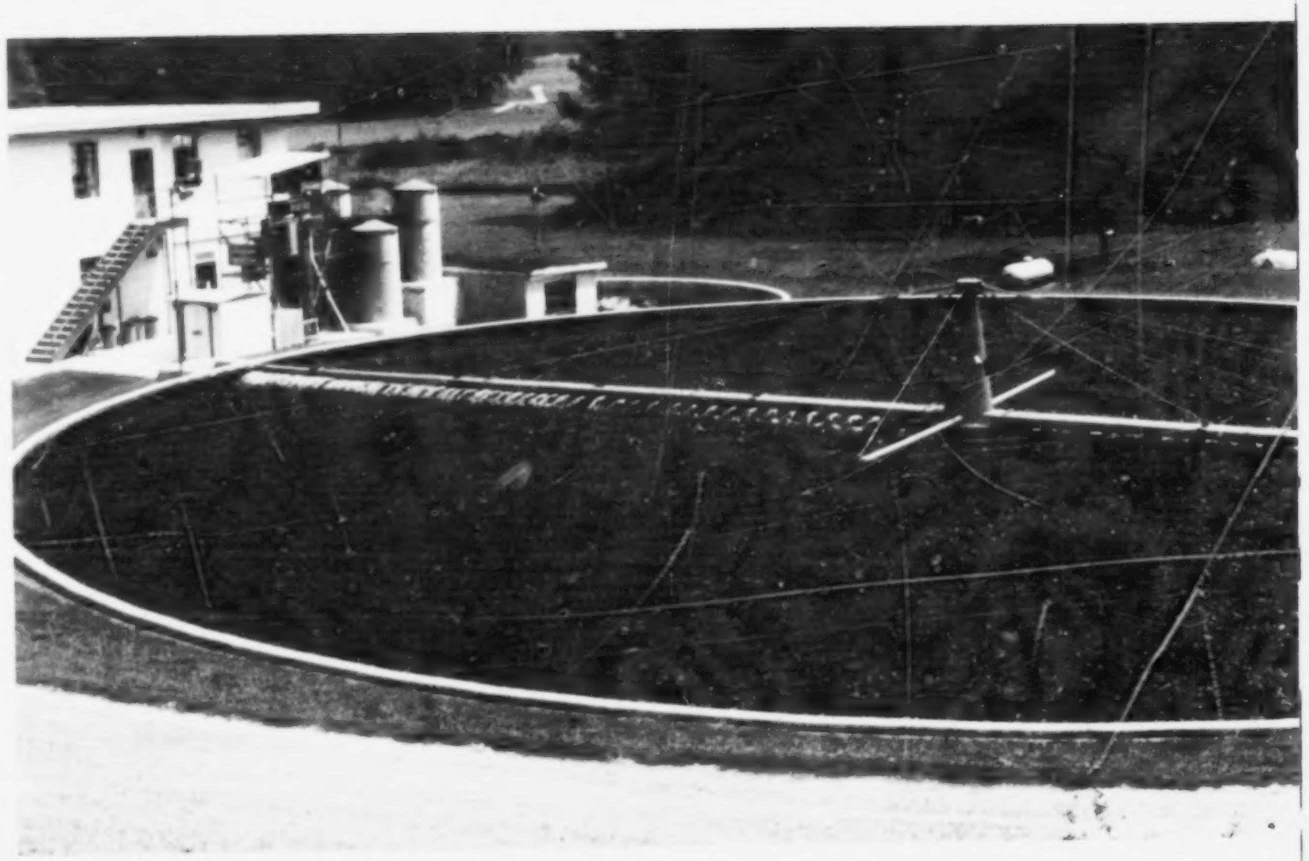
- Trickling filters
- Activated sludge
- Oxidation ponds (or lagoons)

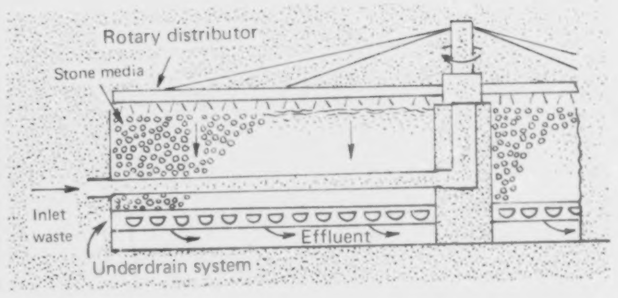
In addition, some relatively new approaches to secondary treatment, which do not fall in any of the above categories, will be discussed. As noted earlier, secondary levels of treatment can also be achieved by nonbiological, physical-chemical processes or by land treatment systems, which are discussed in later sections.

trickling filters

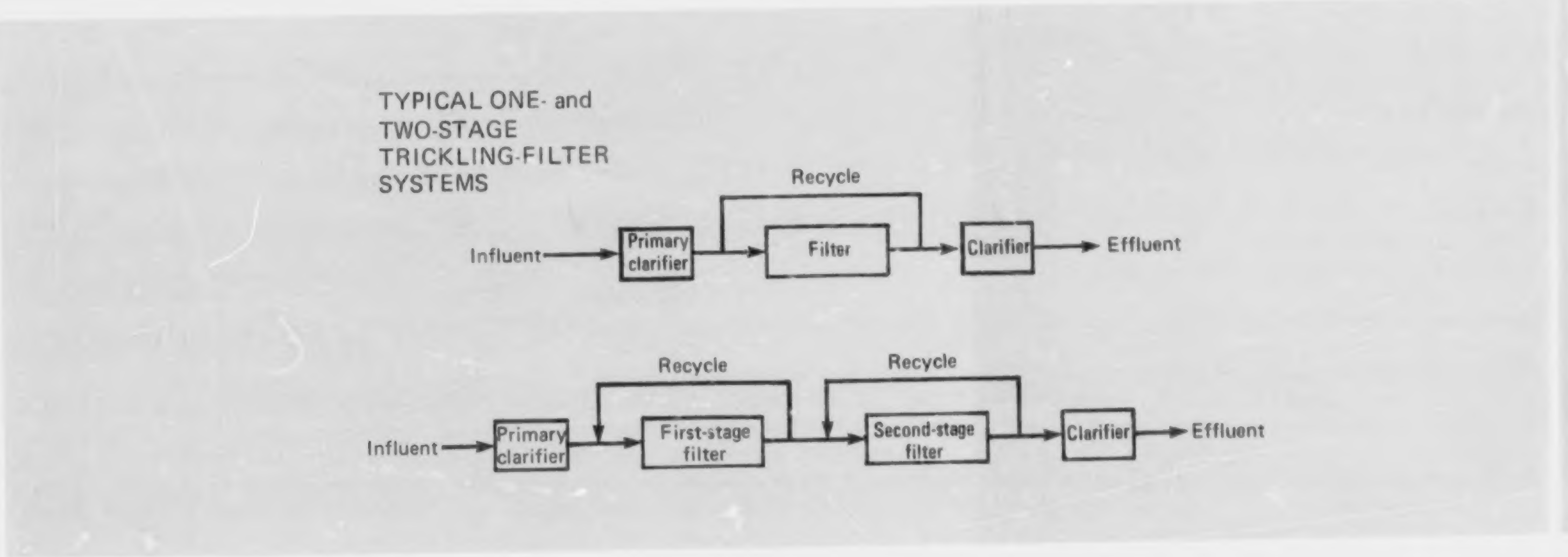
A trickling filter consists of a bed of coarse material, such as stones, slats, or plastic materials, over which wastewater is applied in drops, films, or spray from moving distributors or fixed nozzles, and through which it trickles to underdrains.

As the wastewater trickles through the bed, microbial growth occurs on the surface of the stone or packing in a "fixed film." The wastewater passes over the stationary microbial population to provide the needed contact between the micro-organisms and the organics. Trickling filters have long been a popular biologic treatment process. The most widely used design for many years was simply a bed of stones from 3-10 feet deep through which the wastewater passed. The wastewater is typically distributed over the surface of the rocks by a rotating arm.



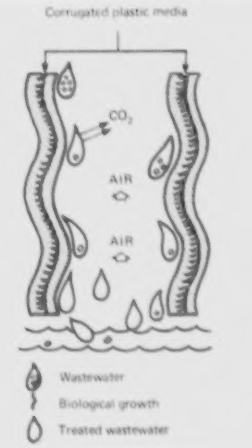

Rotary distributor
Stone media
Inlet waste
Effluent
Underdrain system

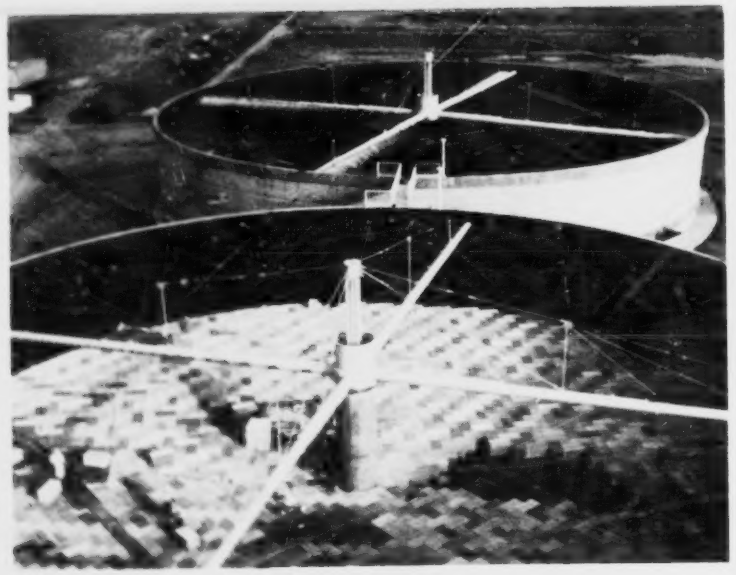
Bacteria gather and multiply on these stones until they consume most of the organic matter in the sewage. The cleaner water trickles out through pipes in the bottom of the filter. Rock filter diameters of up to 200 feet are used. Trickling filters are not primarily a filtering or straining process as the name implies (the rocks in a rock filter are 1-4 inches in diameter, too large to strain out solids), but are a means of providing large amounts of surface area where the micro-organisms cling and grow in a slime on the rocks as they feed on the organic matter. Excess growths of micro-organisms wash from the rock media and would cause undesirably high levels of suspended solids in the plant effluent if not removed. Thus, the flow from the filter is passed through a sedimentation basin to allow these solids to settle out. This sedimentation basin is referred to as a "secondary clarifier" or a "final clarifier" to differentiate it from the sedimentation basin used for primary settling. To prevent the biological slimes from drying out and dying during nighttime periods when wastewater flows are too low to keep the filter wet continuously, filter effluent is often recycled to the trickling filter. Recirculation reduces odor potential and improves filter efficiency as it provides another opportunity for the microbes to attack any organics that escaped the first pass through the filter. Another approach to improving trickling-filter performance or handling strong wastewaters is the use of two filters in series, referred to as a "two-stage" trickling-filter system.

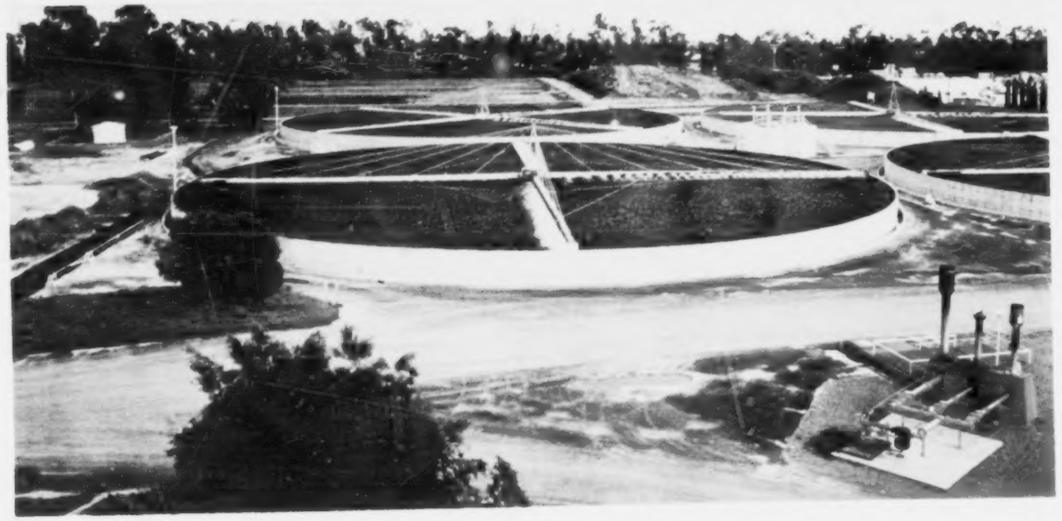

TYPICAL ONE- and TWO-STAGE TRICKLING-FILTER SYSTEMS

Recycle
Influent
Primary clarifier
Filter
Clarifier
Effluent
Recycle
Recycle
Influent
Primary clarifier
First-stage filter
Second-stage filter
Clarifier
Effluent

Although rock trickling filters have performed well for years, certain limitations have become apparent. Under high organic loadings, the slime growths can be so prolific as to plug the void spaces between the rocks, causing flooding and failure of the system. Also, the volume of void spaces is limited in a rock filter, which restricts the circulation of air in the filter and the amount of oxygen available for the microbes. This limitation, in turn, restricts the amount of wastewater that can be processed. To overcome these limitations, other materials for filling the trickling filter have recently become popular. These materials include modules of corrugated plastic sheets, redwood slats, and plastic rings. These media offer larger surface areas for slime growths (typically 27 square feet of surface area per cubic foot as compared to 12-18 square feet per cubic foot for 3-inch rocks) and greatly increase void ratios for increased air flow. The materials are also much lighter than rock (by a factor of about 30), so that the trickling filters can be much taller without facing structural problems. While rock in filters is usually not more than 10 feet deep, synthetic media depths are often 20 feet or more, reducing the overall space requirements for the trickling-filter portion of the treatment plant.







A typical overall efficiency of a trickling-filter treatment plant is about 85 percent removal of BOD and suspended solids for municipal wastewaters, which corresponds to about 30 mg/l of suspended solids and BOD in the final effluent.

Advantages. The basic simplicity of the process is a major advantage. The incoming load of pollutants can vary over a wide range during the day without causing operating problems, minimizing the need for operator skills. The mechanical equipment is simple, making plant maintenance an easy task. Energy requirements for the process are very low in comparison to other secondary treatment processes.

Disadvantages. The process efficiency is affected markedly by air temperature because of the large, fixed surface area of the microbes exposed to the air within the filter. Treatment efficiency falls off in the winter and improves in the summer. The actual contact time between the organics and the microbes is limited and is shorter than that achieved in the activated-sludge process. As a result, some soluble BOD that would be removed by the activated-sludge process escapes a trickling-filter plant. Thus, the overall efficiency is less than that of a well-operated activated-sludge process. Coupled with increasingly rigid treatment requirements, this disadvantage has led to a trend in new plant construction toward the activated-sludge process.

Energy Requirements. Low-rate rock media trickling filters have a low power consumption —about 300 kwh per million gallons treated for the wastewater treatment portion of the plant. High-rate plastic media trickling filters require more power—about 480 kwh per million gallons treated. The power consumption for low-rate rock media trickling filters is much less than that required for the activated sludge process. Trickling filters consume no resources other than power.

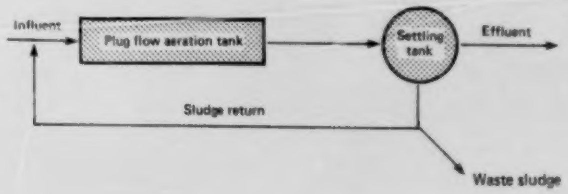
Space Requirements. The precise space requirements for a plant will depend on the design criteria selected by the consultant as best suited for the particular wastewater, the extent of other facilities (such as laboratories, warehouses, shops, etc.), the method of sludge handling used, and the layout best suited for the specific site. Typically, a complete rock trickling plant will occupy about 1 acre per mgd capacity. Taller filters packed with synthetic media can reduce the total space requirements by a factor of about 2.

Costs. Based on late 1977 price levels, the cost of trickling filter treatment (including primary treatment but not sludge processing) ranges from 75-85 cents per 1,000 gallons at 1 mgd to 35-40 cents per 1,000 gallons at 10 mgd. These costs are equivalent to $7.90-$8.95 per month per home at 1 mgd and $3.70-$4.20 per month per home at 10 mgd.

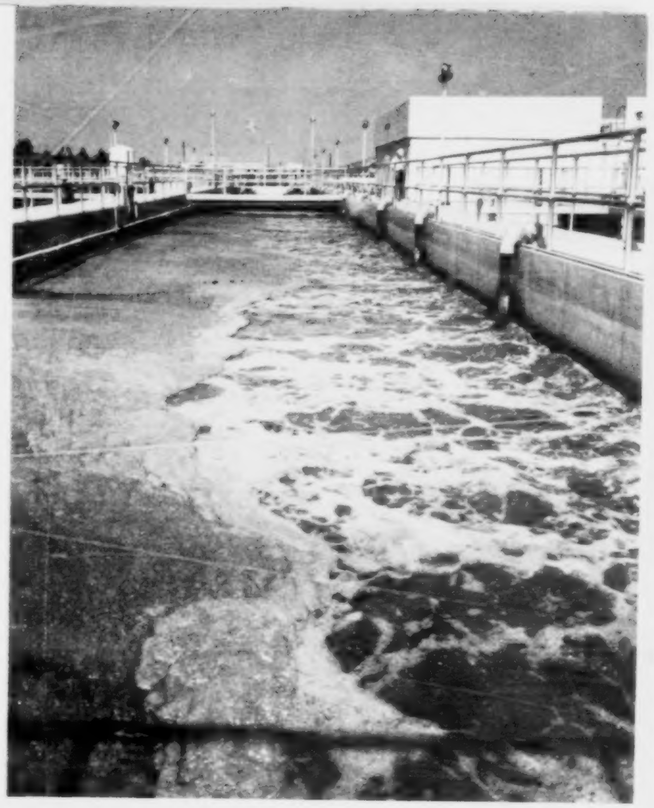
activated sludge

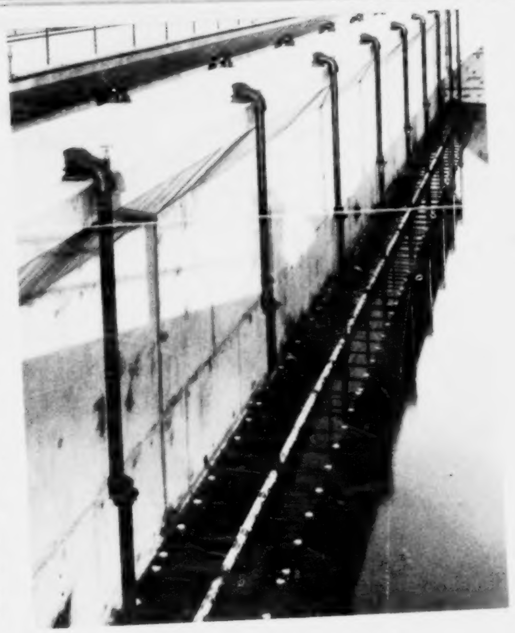
The activated-sludge process is a biological wastewater treatment technique in which a mixture of wastewater and biological sludge (micro-organisms) is agitated and aerated. The biological solids are subsequently separated from the treated wastewater and returned to the aeration process as needed.

The activated-sludge process derives its name from the biological mass formed when air is continuously injected into the wastewater. Under such conditions, micro-organisms are mixed thoroughly with the organics under conditions that stimulate their growth through use of the organics as food. As the micro-organisms grow and are mixed by the agitation of the air,


Influent
Plug flow aeration tank
Settling tank
Effluent
Sludge return
Waste sludge

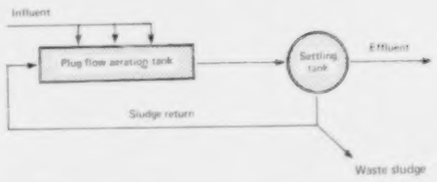
CONVENTIONAL ACTIVATED SLUDGE



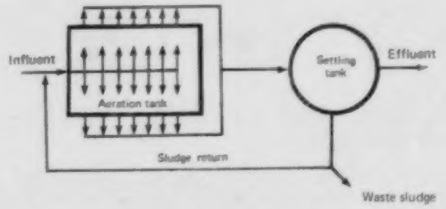


the individual organisms clump together (flocculate) to form an active mass of microbes called "activated sludge." In practice, the wastewater flows continuously into an aeration tank where air is injected to mix the activated sludge with the wastewater and to supply the oxygen needed for the microbes to break down the organics. The mixture of activated sludge and wastewater in the aeration tank is called "mixed liquor." The mixed liquor flows from the aeration tank to a secondary clarifier where the activated sludge is settled out. Most of the settled sludge is returned to the aeration tank to maintain a high population of microbes to permit rapid breakdown of the organics. Because more activated sludge is produced than can be used in the process, some of the return sludge is diverted or "wasted" to the sludge-handling system for treatment and disposal. In conventional activated-sludge systems, the wastewater is typically aerated for 6-8 hours in long, rectangular aeration basins with about 1 cubic foot of air injected uniformly along the length of the aeration basin for each gallon of wastewater treated. Air is introduced either by injecting it into diffusers near the bottom of the aeration tank or by mechanical mixers located at the surface of the aeration tank. The volume of sludge returned to the aeration basin is typically 20-30 percent of the wastewater flow. There are many variations of this conventional system that have evolved over the years and that have improved the process performance, as described in the following paragraphs.

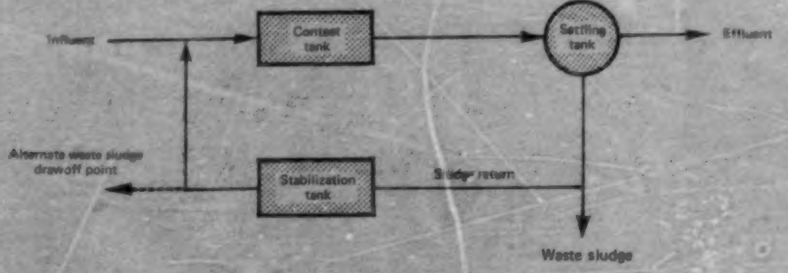
Early in the use of the conventional process, it was found that the demand for oxygen in the aeration tank was much greater at the inlet end of the aeration basin, where the stronger incoming wastewater entered, than at the outlet end, where most of the oxygen-demanding materials had been stabilized. This discovery led to the *tapered aeration* process, where a greater


Influent
Plug flow aeration tank
Settling tank
Effluent
Sludge return
Waste sludge

STEP AERATION


Influent
Aeration tank
Settling tank
Effluent
Sludge return
Waste sludge

COMPLETE MIX

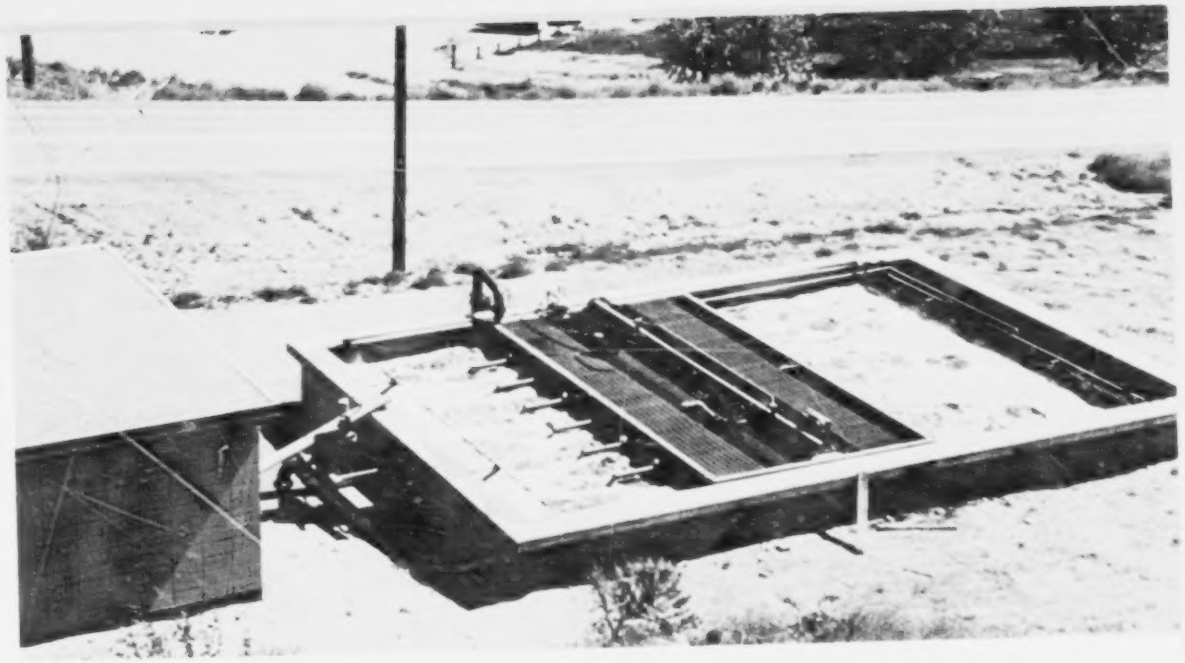

Influent
Contact tank
Settling tank
Effluent
Alternate waste sludge drawoff point
Stabilization tank
Sludge return
Waste sludge

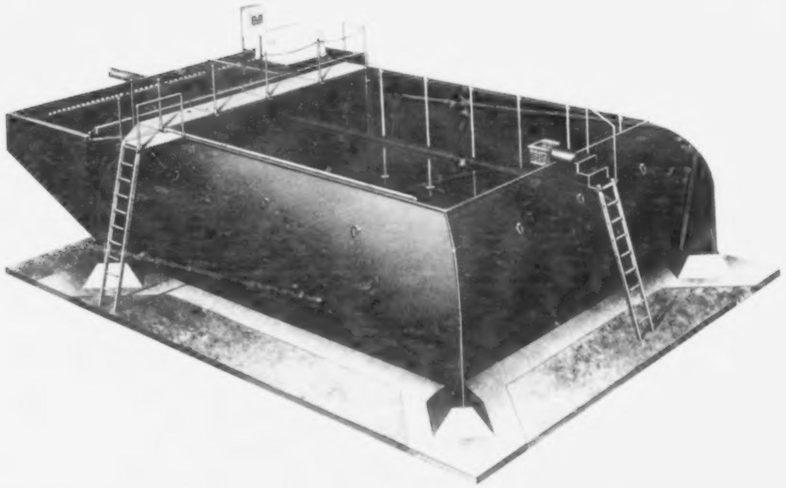
CONTACT STABILIZATION

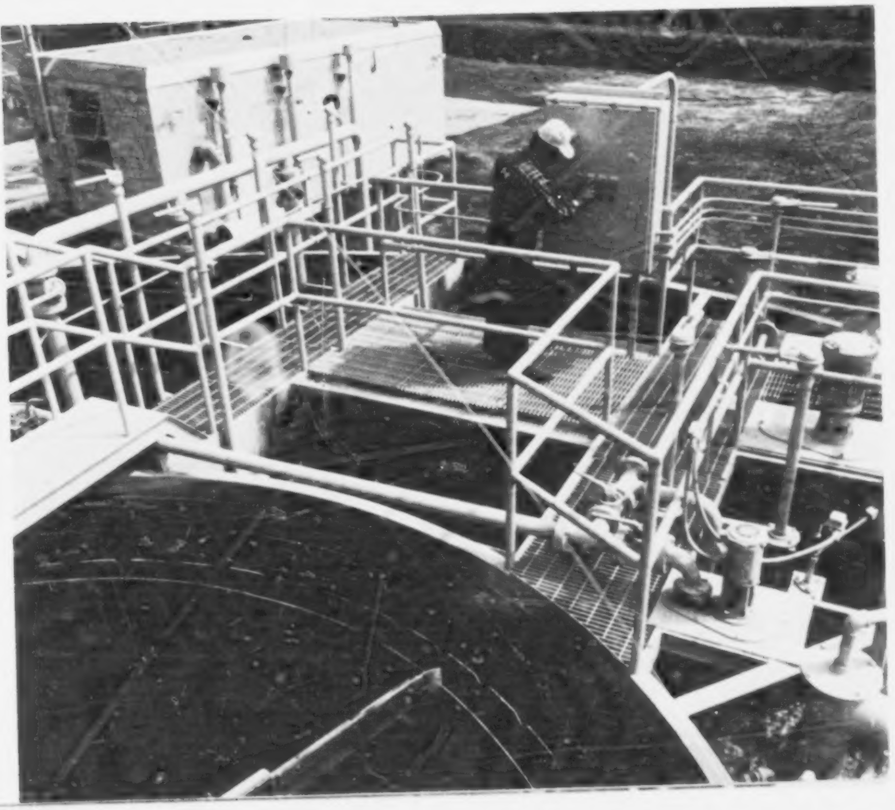
portion of the air was injected at the inlet end than at the outlet end of the aeration basin. The quantity of air used was the same, but its distribution was tapered along the aeration tank. Another variation evolved in which the wastewater flow was introduced at several points rather than all at once. Although it is actually a step feeding of wastewater, the process is known as *step aeration*. Multiple feed points spread the oxygen demand over more of the aeration basin, which results in more efficient use of the oxygen. Existing conventional plants are often modified to the step aeration process to increase their capacity. To extend even further the benefits achieved with step aeration, the *complete mix* activated-sludge concept may be used. In this system, the influent wastewater is dispersed as uniformly as possible along the entire length of the aeration basin, so that the oxygen demand is uniform from one end to the other.

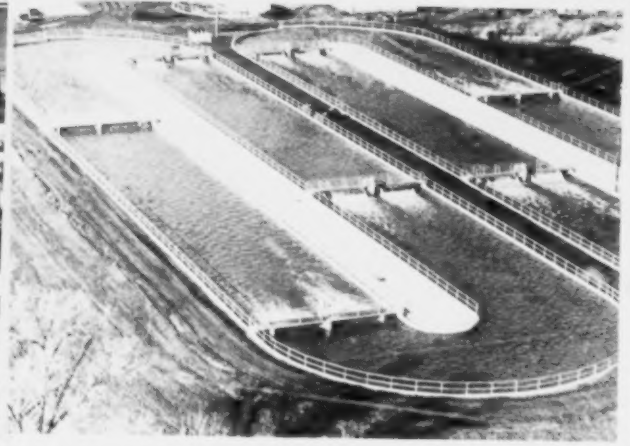
Another variation of activated sludge is the *contact stabilization* process. In this approach, the incoming wastewater is mixed briefly (20-30 minutes) with the activated sludge—just long enough for the microbes to absorb the organic pollutants from solution but not long enough for them to actually break down the organics. The activated sludge is then settled out and returned to another aerated basin (stabilization tank), in which it is aerated for 2-3 hours to permit the microbes to break down the absorbed organics. Because the settled volume of the activated sludge being aerated is much smaller than the total wastewater flow, the total size of the plant is reduced.

Many small activated-sludge plants, often sold as prefabricated steel package plants, use the *extended aeration* form of activated sludge. The process flow diagram is essentially the same as in the complete mix system, except that these small plants typically have no primary treatment and aerate the raw wastewater for a 24-hour period rather than the 6-8 hours used in conventional plants. The long aeration period allows the activated sludge formed to be partially digested within the aeration tank so that it can be dewatered and disposed of without the need for large sludge digestion capacity.



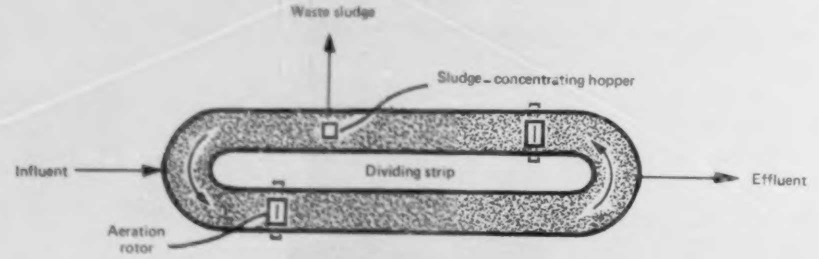






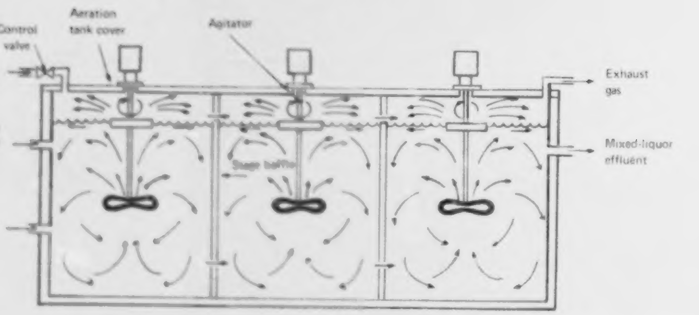
A variation of the conventional process, called the *oxidation ditch*, was developed in the Netherlands and has found use in the United States. A surface-type aerator is used that provides aeration and circulates the wastewater through the ditch.

Since 1970, there has been a great deal of interest in systems using *pure oxygen* as a substitute for air. The potential of oxygen aeration has resulted in rapid acceptance by consulting engineers, municipalities, and industries. The first full-scale application of this process to the treatment of municipal wastewater occurred in 1969 under a demonstration contract from the U.S. Environmental Protection Agency (EPA). In this demonstration project, a total of 1.25 mgd of sewage was treated. Today, there are many large full-scale municipal wastewater treatment plants actually using oxygen aeration systems. To provide efficient use of the oxygen, the aeration tanks are often covered and the oxygen is recirculated through several stages. When the tanks are covered, high-purity oxygen (over 90 percent) enters the first stage of the system and flows through the oxygenation basin concurrently with the wastewater under treatment. Pressure under the tank covers is essentially atmospheric and sufficient to maintain control and prevent backmixing from stage to stage. This system allows for efficient oxygen use at low power requirements. Mixing within each stage can be accomplished either with surface aerators or with a submerged rotating-sparge system. As an alternative to the use of covered basins, specially designed oxygen diffusers can be used in open basins.


Waste sludge
Sludge-concentrating hopper
Influent
Dividing strip
Effluent
Aeration rotor

OXIDATION DITCH

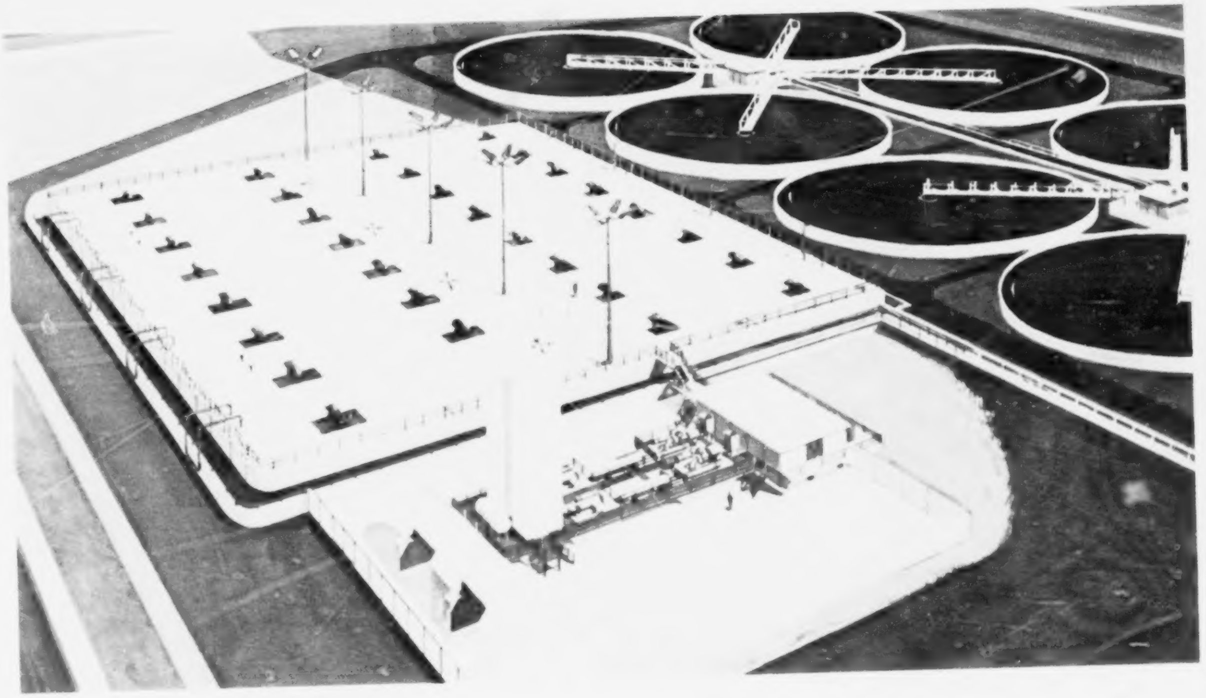
SCHEMATIC DIAGRAM OF MULTISTAGE OXYGEN AERATION SYSTEM


Control valve
Aeration tank cover
Agitator
Oxygen feed gas
Exhaust gas
Waste liquor feed
Stage baffle
Mixed-liquor effluent
Recycle sludge

The number of stages and the type of mixing device selected are variables that depend on waste characteristics, plant size, land availability, treatment requirements, and other similar considerations. Pure oxygen allows the use of much smaller aeration tanks (1.5-2 hours' aeration rather than 6-8 hours), typically produces a better settling activated sludge than conventional air systems, and produces a sludge that is easier to dewater. The oxygen used in the process is typically generated onsite. The potential advantages of the process have led many localities to adopt this approach, including Detroit, Michigan (900 mgd); New Orleans, Louisiana (122 mgd); Middlesex County, New Jersey (120 mgd); Louisville, Kentucky (105 mgd); Denver, Colorado (72 mgd); Montgomery County, Maryland (60 mgd); Miami, Florida (55 mgd); Euclid, Ohio (22 mgd); New York City (20 mgd); Salem, Oregon (16 mgd); Deer Park, Texas (6 mgd); Tahoe Truckee Sanitation Agency, California (5 mgd); and Littleton-Englewood, Colorado (20 mgd).

By now it is apparent that there are many variations of the activated-sludge process, each of which has advantages and disadvantages relative to the others. The general process of activated-sludge treatment, however, does have some identifiable advantages and disadvantages.

Advantages. The process is versatile because the design can be tailored to handle a wide variety of raw wastewater compositions and to meet a variety of effluent standards. The process is capable of producing a higher quality effluent than the trickling-filter process. A properly designed and operated activated-sludge plant removes essentially all soluble BOD. The secondary effluent BOD is made up primarily of the oxygen demand exerted by the suspended solids in the effluent. Typical effluent quality is 20-25 mg/l BOD and 20-25 mg/l suspended solids, although, with careful operation, the process has produced less than 10 mg/l BOD and suspended solids at some plants. The process is usually lower in capital costs than a trickling-filter plant and requires less area.



Disadvantages. The process requires careful operational control—more than that required by a trickling filter. Energy requirements are also higher.

Energy Requirements. The power requirements vary considerably with the activated-sludge process variation and can range from 600-900 kwh per million gallons.

Space Requirements. Typically, a conventional activated-sludge plant occupies about 0.5 acre per mgd capacity. The pure oxygen system significantly reduces space requirements.

Costs. Based on the 1977 prices, overall activated-sludge treatment costs (exclusive of sludge disposal costs) range from 85-95 cents per 1,000 gallons at 1 mgd to 35-40 cents per 1,000 gallons at 10 mgd. These costs are equivalent to $8.95-$10.00 per month per home at 1 mgd and $3.70-$4.20 per month per home at 10 mgd.

oxidation ponds

Oxidation ponds (also called "lagoons" or "stabilization ponds") are large shallow ponds designed to treat wastewater through the interaction of sunlight, wind, algae, and oxygen. They are one of the most commonly employed secondary systems and account for about one-third of all secondary plants in the United States. About 90 percent of the ponds are used in towns with less than 10,000 people (1-mgd capacity). Primary treatment is sometimes used as pretreatment, but the added cost is usually not justified. Typically, raw wastewater enters the pond at a single point in the middle of the pond or at one edge. Ponds are usually 2-4 feet deep—at least deep enough to prevent weed growths but not deep enough to prevent mixing by wind currents. Shallow ponds are usually aerobic—that is, oxygen is present—through nearly all depths, except the anaerobic (devoid of oxygen) sludge layer on the bottom of the pond. Some ponds have been designed (and have worked well) with depths of 10-20 feet, where the anaerobic bottom zone becomes a greater portion of the overall system. The pond may have sufficient volume to accommodate from 15-60 days of wastewater flow, and it may be a fill-and-draw or continuous flow-through operation. Algae grow by taking energy from the sunlight and consuming the carbon dioxide and inorganic compounds released by the action of the bacteria in the pond. The algae, in turn, release oxygen needed by the bacteria to supplement the oxygen introduced into the pond by wind action. The most critical factor is to insure that enough oxygen will be present in the pond to maintain aerobic conditions; if oxygen is insufficient, odor problems will occur. The sludge deposits from the pond eventually must be removed by dredging.

Ponds are sometimes designed with several cells in parallel to distribute the wastewater better and avoid localized zones of high oxygen demand caused by uneven deposits of sludges. Several smaller parallel cells also reduce the problems that can be encountered with wave action in large ponds. Ponds are sometimes placed in a series for highly polluted wastes or to permit use of the last pond in a series as a polishing step to provide higher removals of suspended solids. Pond effluent is sometimes recirculated to improve mixing in the pond.

To eliminate the dependence on algal-produced oxygen and to reduce the area required by the ponds, aeration equipment is sometimes installed in the pond to supply oxygen. Such a system is called an *aerated lagoon*. Air can be supplied by a compressor that injects air into the pond through tubing installed on the pond bottom or by mechanical aerators installed at the surface of the pond. Aerated ponds are typically about one-fifth the size of a conventional oxidation pond and are actually a form of the activated-sludge process. Aerated lagoons are usually followed by a quiescent, second-stage pond to remove the suspended solids from the aerated-lagoon effluent.

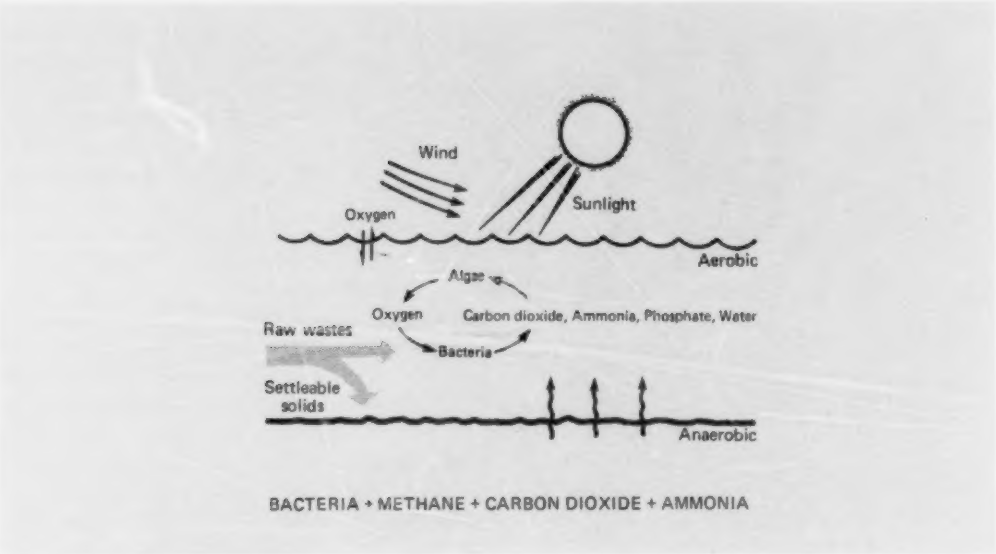
Oxidation ponds usually meet secondary treatment requirements for removal of BOD, but frequently fail to meet secondary requirements for suspended solids removal because of the presence of algae in the pond effluent. Much work is currently underway on various methods of removing these algae; the most promising alternatives to date are filtration through sand beds at low rates, filtration through a bed of rocks that may be a part of the dike system, and a combination of chemical treatment of the pond effluent and settling. These polishing techniques may produce a degree of treatment that exceeds the requirements for secondary removals of both BOD and suspended solids. Some municipalities have already decided to use polishing systems on their existing lagoons to meet new treatment standards rather than abandon the ponds in favor of an all-new treatment system.

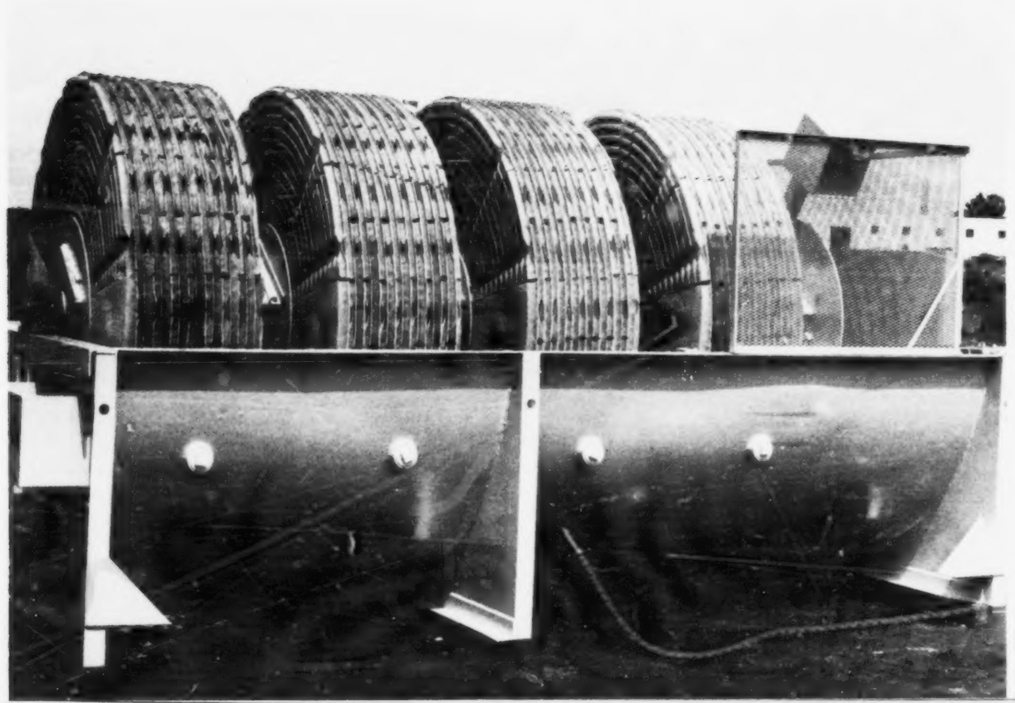
Advantages. Oxidation ponds are easy to construct, operate, and maintain. They are low in construction costs and there is no mechanical equipment to maintain. Because of their long detention time, they are effective in removing disease-causing organisms.

Disadvantages. The relatively large space requirements for conventional ponds are a disadvantage in many areas and for large cities. Because the ponds are simple to operate, some towns have virtually ignored them after installation, resulting in weed growths on the dikes and even dike failures, in some cases, caused by animals burrowing into the dikes. The frequent need for removal of algae from the effluent to meet secondary treatment requirements fully is a disadvantage. Many systems for removal of these algae introduce more complex operating and maintenance requirements and higher costs.

Energy Requirements. Oxidation ponds do not consume power unless artificially aerated. Completely mixed, aerated lagoons can use more energy than the activated-sludge process.

Space Requirements. The actual require-


Wind
Oxygen
Sunlight
Aerobic
Algae
Oxygen
Carbon dioxide, Ammonia, Phosphate, Water
Raw wastes
Bacteria
Settleable solids
Anaerobic
BACTERIA + METHANE + CARBON DIOXIDE + AMMONIA



ments depend on the climate, but typically range from 35 acres per mgd capacity for nonaerated ponds in warm climates to 85 acres per mgd in cold climates using conventional 4-foot-deep lagoons.

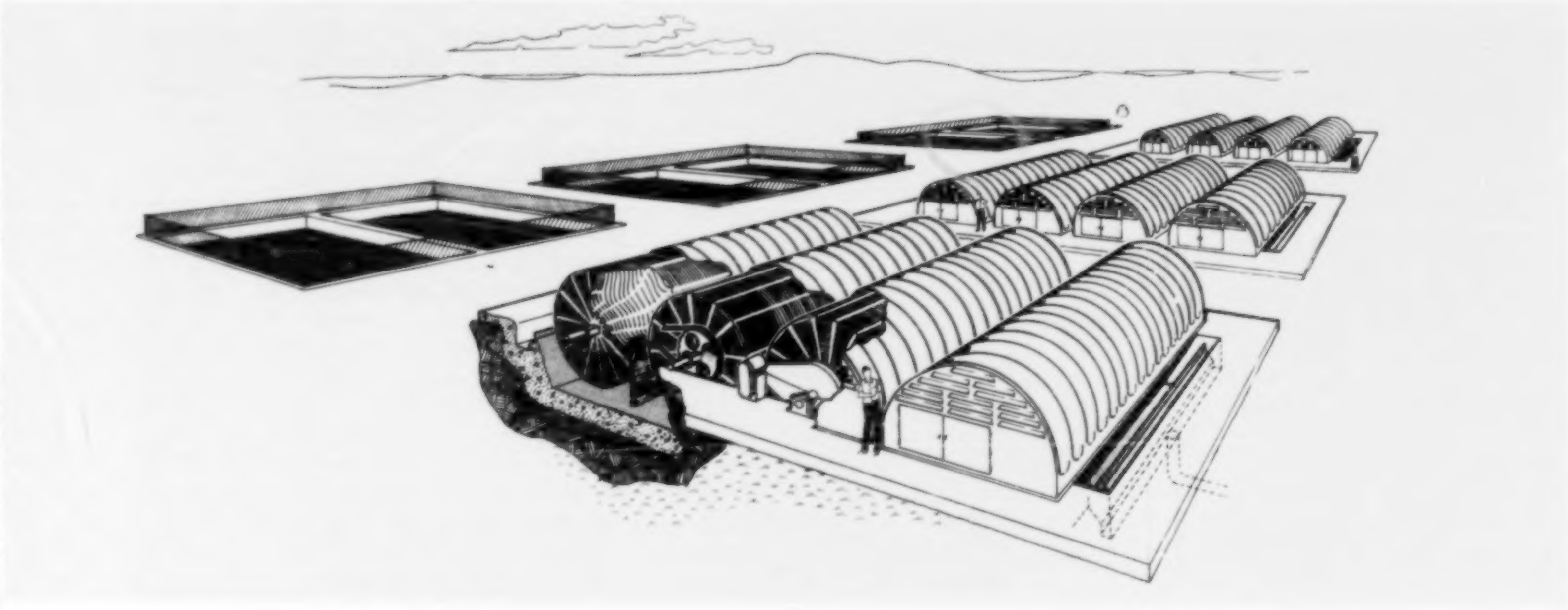
Costs. The construction costs for a pond range from about $3,000 per acre for ponds greater than 25 acres to $6,000-$12,000 per acre for ponds of 4 acres or less (excluding land costs). Operation and maintenance costs are usually about 20-25 percent of those for trickling-filter or activated-sludge plants. Total treatment costs for a 1-mgd plant will typically be less than 20 cents per 1,000 gallons ($2.10 per month per home)—much less than activated-sludge or trickling-filter treatment at the same capacity. To this cost, however, the cost of removing algae from the pond effluent must often be added to meet secondary standards fully. These added costs may be as high as 10 cents per 1,000 gallons (5-7 cents has been estimated for sand filters without the use of chemicals).

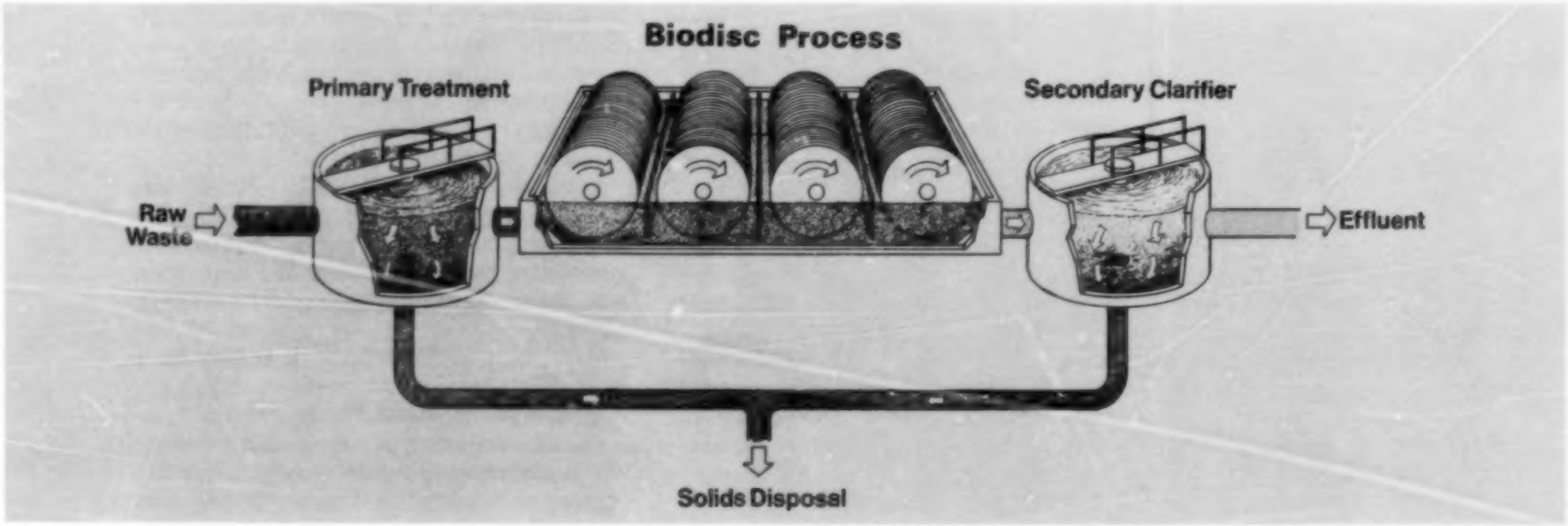
other secondary processes

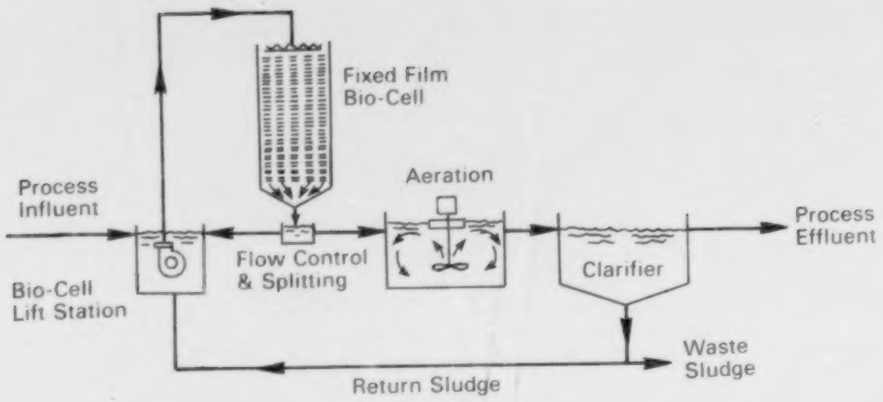
There are two other processes which do not fit precisely into the activated-sludge or trickling-filter categories, but do capitalize on some of the best features of both. These processes are

- Rotating biological contactors
- Activated biofilter

Rotating Biological Contactors. This process (also referred to as biodiscs or rotating biological surfaces) consists of a series of closely spaced discs (10-12 feet in diameter) mounted




Biodisc Process
Primary Treatment
Secondary Clarifier
Raw Waste
Effluent
Solids Disposal



ACTIVATED-BIOFILTER PROCESS

on a horizontal shaft and rotated while about one-half of their surface area is immersed in wastewater. The process has been used in Europe for several years. The discs are typically constructed of lightweight plastic. When the process is placed in operation, the microbes in the wastewater begin to adhere to the rotating surfaces and grow there until the entire surface area of the discs is covered with a 1/16-1/8-inch layer of biological slimes. As the discs rotate, they carry a film of wastewater into the air, where it trickles down the surface of the discs, absorbing oxygen. As the discs complete their rotation, this film mixes with the reservoir of wastewater, adding to the oxygen in the reservoir and mixing the treated and partially treated wastewater. As the attached microbes pass through the reservoir, they absorb other organics for breakdown. The excess growth of microbes is sheared from the discs as they move through the reservoir. These dislodged organisms are kept in suspension by the moving discs. Thus, the discs serve several purposes. They provide media for the buildup of attached microbial growth, bring the growth into contact with the wastewater, and aerate the wastewater and suspended microbial growth in the wastewater reservoir. The speed of rotation is adjustable. The attached growths are similar in concept to a trickling filter, except that the microbes are passed through the wastewater rather than the wastewater being passed over the microbes. Some of the advantages of both the trickling-filter and activated-sludge processes are realized. As the treated wastewater flows from the reservoir below the discs, it carries the suspended growths out to a downstream settling basin for removal. The process can achieve secondary effluent quality or better. By placing several sets of discs in series, it is possible to achieve even higher degrees of treatment—including biological conversion of ammonia to nitrates if desired. The process is being used or planned for use at several United States installations, including those at Battleground, Washington; Boynton Beach, Florida; Cadillac, Michigan; Hopkinton, Iowa; Omaha, Nebraska; Selden, Long Island, New York; Edgewater, New Jersey; Whitewater, Wisconsin; and Orlando, Florida.

Advantages. There are no sludge or effluent recycle streams. The mechanical equipment is low speed, easing maintenance. Higher degrees of treatment are obtained than in a trickling filter. The bulk (95 percent) of the microbes is attached to the discs, making them less susceptible to washout and upset than in an activated-sludge plant. The process requires fewer process decisions by the operator than does activated sludge. Because of the low hydraulic headloss through the process, rotating biological contactors frequently can be added to an existing plant to improve performance without the need to add pumping facilities.

Disadvantages. The disc process must be covered for protection against freezing, precipitation, wind, and vandalism. Efficiency is adversely affected by cold temperatures unless the treatment building is heated.

Energy Requirements. Depending upon the hydraulic loading used in design of the rotating biodisc process, energy requirements range from about 400-900 kwh per million gallons treated.

Space Requirements. The overall plant space requirements are about 0.5 acre per mgd of capacity.

Costs. The costs for treatment using rotating biological contactors generally range from 75-85 cents per 1,000 gallons at 1 mgd ($7.90-$8.95 per month per home) to about 45 cents per 1,000 gallons for a 10-mgd plant ($4.75 per month per home).

Activated Biofilters. This process combines an attached growth system with recirculation of activated sludge over and through the media. In addition to recirculating the effluent, as is typically done in a trickling filter, the process also recirculates settled sludge from the secondary clarifier. The trickling-filter media used in this system is made up of redwood slats. Through sludge recirculation, it is possible to build up a level of suspended microbes comparable to that in an activated-sludge system in addition to the population of microbes which are attached to the redwood media. Oxygen is supplied by the splashing of the wastewater between layers of the redwood slats and by the movement of the wastewater in a film across the microbial layer attached to the slats. The typical depth of the redwood media is 14 feet.

An aeration tank is often installed between the filter and the secondary clarifier to provide high degrees of treatment. With about 1 hour of supplemental aeration, the process will produce an effluent with less than 20 mg/l BOD and suspended solids. When supplemental aeration is used, the redwood filter size can be reduced somewhat, and overall costs may actually be reduced because of lower waste sludge quantities. The process is in use at Madera, California (10 mgd); Idaho Falls, Idaho (17 mgd); Freemont (10.5 mgd) and Burwell (0.5 mgd), Nebraska; Henderson (15 mgd) and Owensboro (8 mgd), Kentucky; Longmont, Colorado (2.5 mgd); Mt. Vernon, Washington (4 mgd); Kalispell (3 mgd) and Helena (6.2 mgd), Montana; and Forest Grove, Oregon (21 mgd).

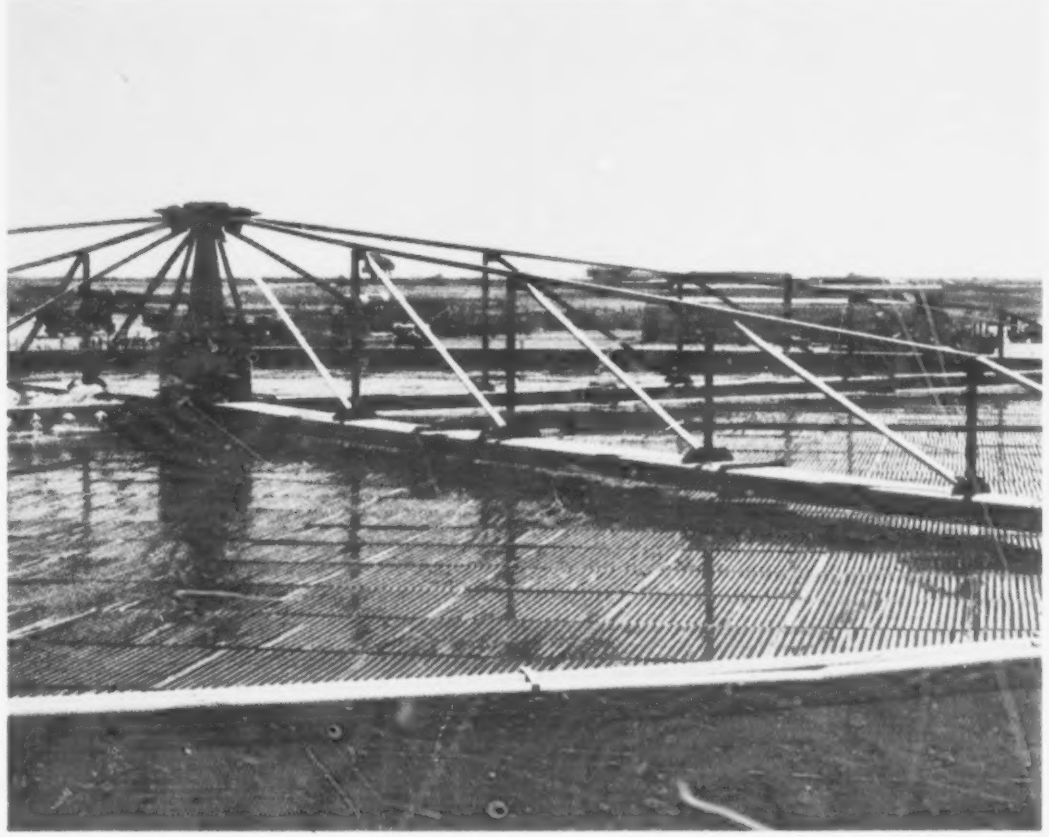
Advantages. The combination of fixed microbial growth and high concentration of suspended growths provides stable operation and minimizes system upsets. The process can be added ahead of existing activated-sludge basins to increase plant capacity or efficiency. The process requires less area than a trickling-filter plant and is less sensitive to cold temperature effects.

Disadvantages. The supplemental aeration process discussed earlier is often needed to meet secondary treatment standards. Although finding increased use, the process is relatively new and there is no long-term experience to draw from.

Energy Requirements. Power requirements, with supplemental aeration, are about 630 kwh per million gallons treated.

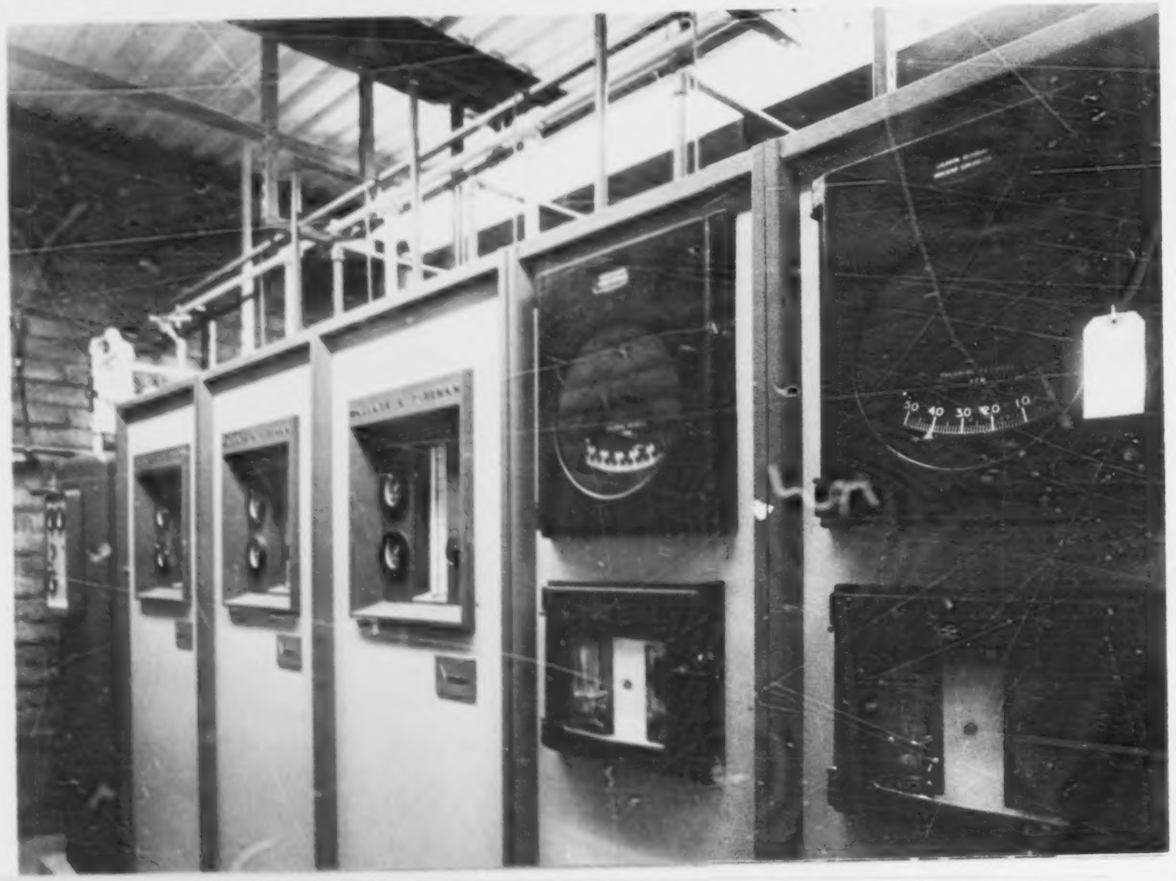
Space Requirements. The overall space requirements are comparable to an activated-sludge plant—about 0.5 acre per mgd.

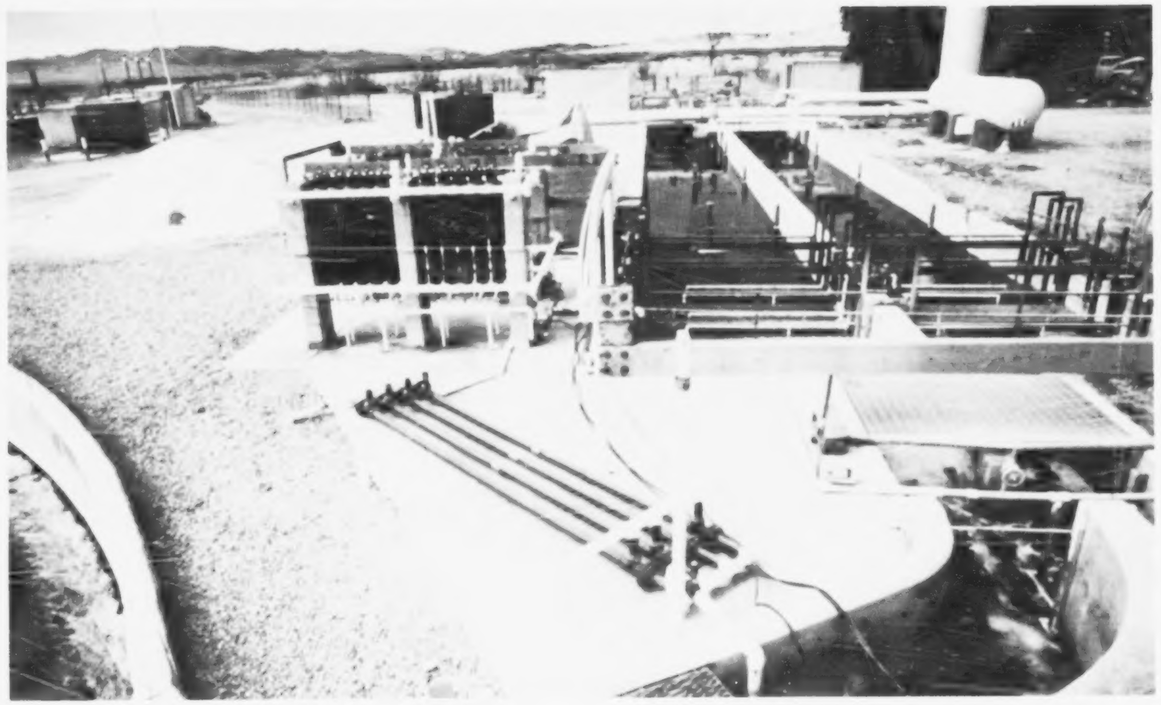
Costs. The cost of the process at 1 mgd is about 85 cents per 1,000 gallons ($8.95 per month per home) and, at 10 mgd, is about 30 cents per 1,000 gallons ($3.15 per month per home).



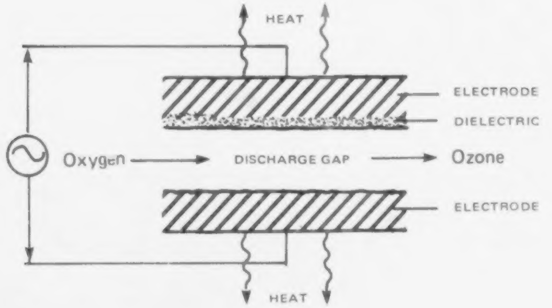
disinfection

Disinfection is the killing of pathogenic (disease-causing) bacteria and viruses found in wastewaters. This process differs from sterilization, which is the killing of all living organisms. The last treatment step in a secondary plant is the addition of a disinfectant to the treated wastewater. The addition of chlorine gas or some other form of chlorine, which is called chlorination, is the process most commonly used for wastewater disinfection in the United States. The chlorine is injected into the wastewater by automated feeding systems. The wastewater then flows into a basin, where it is held for about 30 minutes to allow the chlorine to react with the pathogens. Chlorine is used primarily in two forms: as a gas, or as a solid or liquid chlorine-containing hypochlorite compound. Gaseous chlorine is generally considered the least costly form of chlorine that can be used in large facilities, but it can cause safety hazards if not handled properly. Hypochlorite forms have been used primarily in small systems (less than 5,000 persons), or in large systems, where safety concerns related to handling chlorine gas outweigh economic factors. Although there is concern about the formation of some byproducts resulting from chlorination, the use of chlorine has proven to be a very effective means of disinfecting wastewaters and water supplies. To insure a constant supply of chlorine and to avoid problems of transporting chlorine through surrounding residential areas, some municipalities have elected to build facilities at their wastewater treatment plants to generate their own chlorine or hypochlorite from salt (sodium chloride).





OZONE GENERATION

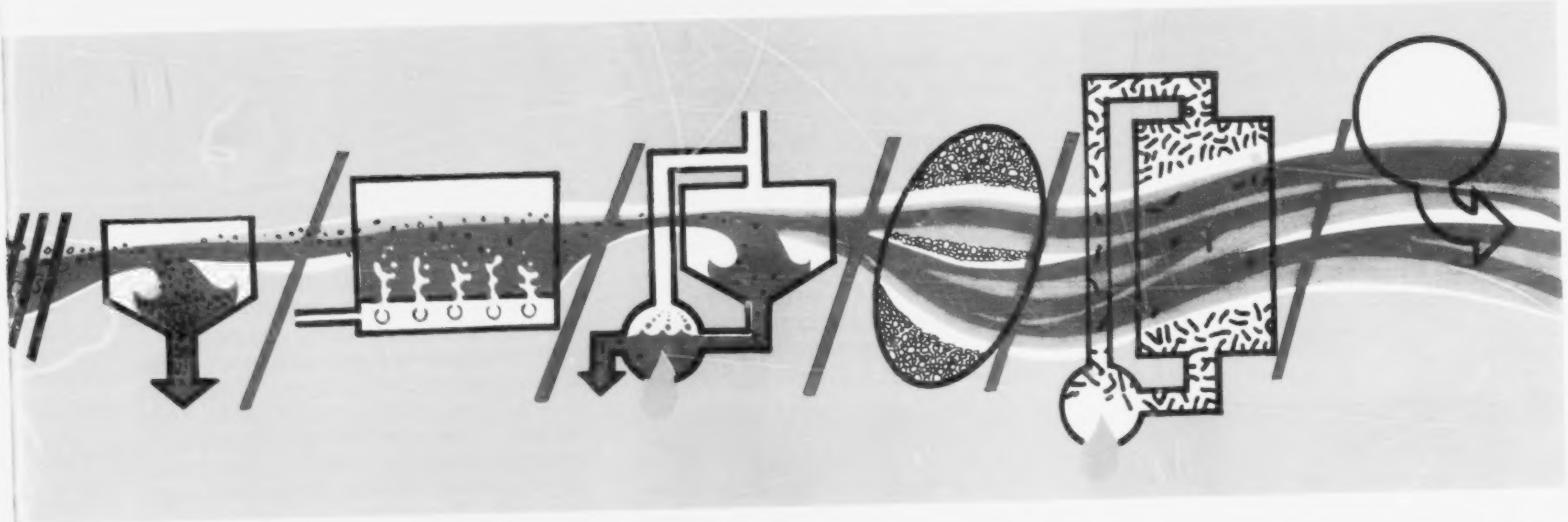


An alternative to chlorine is ozone, which is widely used in Europe for disinfection of water supplies. Ozone is produced at its point of use by passing dry air between two high-potential electrodes to convert oxygen into ozone. Recent improvements in the technology of ozone production have bettered the reliability and economy of its generation. The advantages of using ozone are that it has the best germicidal effectiveness of all known substances and that the only residual material left in the wastewater is more dissolved oxygen. The electrical generation of ozone is an energy-intensive operation. Because ozone must be produced electrically as it is needed and cannot be stored, it is difficult to adjust treatment to variations in ozone demand. The ozonation process is included in the design of a 4-mgd wastewater treatment plant in Mahoning County, Ohio, and several smaller plants using ozone are under design or construction. However, there is not yet any significant full-scale wastewater experience with the process in the United States.

Energy Requirements. Power requirements for chlorination are about 25 kwh per million gallons treated. Power requirements for ozonation are higher—ranging from 160 kwh for oxygen feed to 410 kwh for air feed.

Costs. The cost of ozone is typically higher than the cost of the chlorine required to accomplish the same degree of disinfection. For a 1-mgd plant, the cost of chlorination is less than 5 cents per 1,000 gallons (50 cents per home per month). For a 10-mgd plant, chlorination costs are less than 2 cents per 1,000 gallons (about 20 cents per home per month).

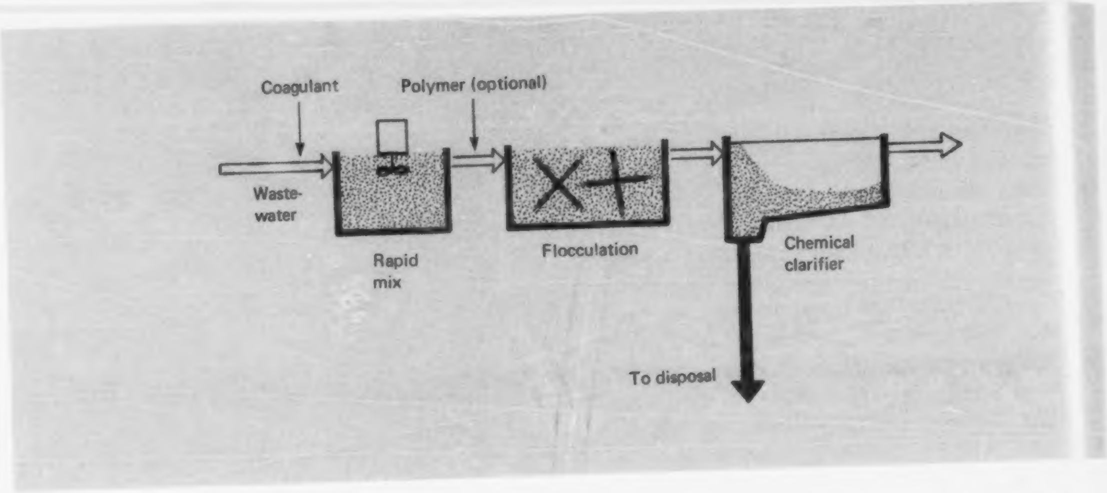
advanced wastewater treatment



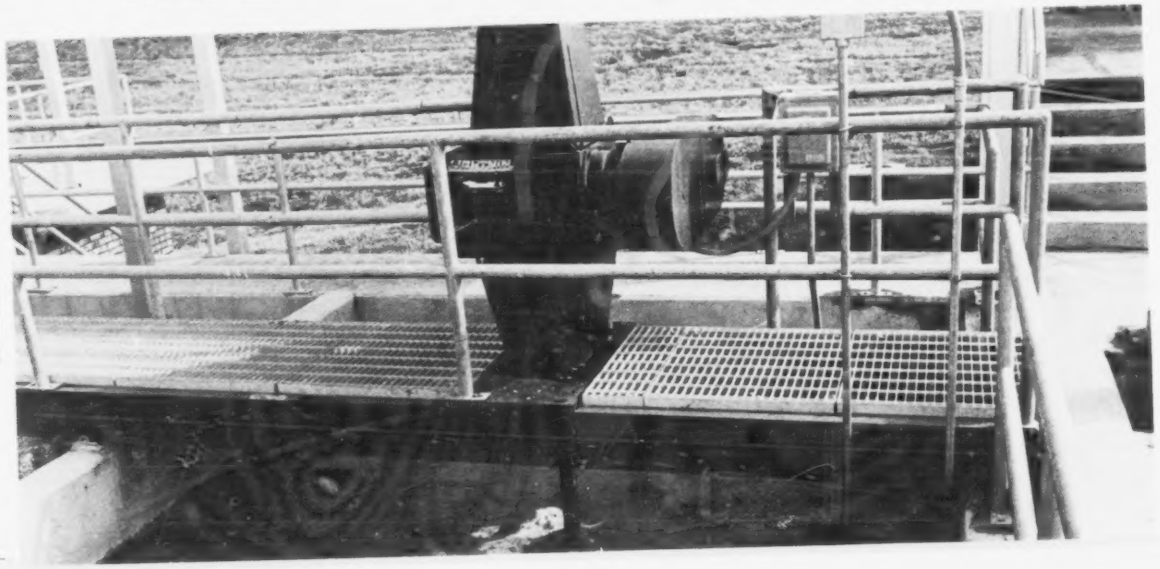
Although secondary treatment processes, when coupled with disinfection, may remove over 85 percent of the BOD and suspended solids and nearly all pathogens, only minor removals of some pollutants—such as nitrogen, phosphorus, soluble COD, and heavy metals—are achieved. In some circumstances, the pollutants contained in a secondary effluent are of major concern. In these cases, processes capable of removing pollutants not adequately removed by secondary treatment are used in what is called "tertiary wastewater treatment" (these processes have often been called advanced wastewater treatment, or AWT for short). The following sections describe available AWT processes. In addition to solving tough pollution problems, these processes improve the effluent quality to the point that it is adequate for many reuse purposes and may convert what was originally a wastewater into a valuable resource too good to throw away.

phosphorus removal

Phosphorus has been identified as one of the key factors in the disruption of the ecological balance of our waters. To meet water quality standards, many cities will be required to reduce phosphorus to low concentrations in wastewater discharges. Excess phosphorus enters our lakes and streams and stimulates the growth of algae and other aquatic life forms and causes them to grow in great profusion. This overabundance of algae in our lakes and streams causes objectionable odors and eventually results in depletion of the water—thus killing off, or limiting, fish population. In conventional wastewater treatment facilities, phosphorus is not removed to any appreciable extent. Available processes now allow for effective removal of phosphorus by relatively minor modifications to existing municipal wastewater treatment facilities.

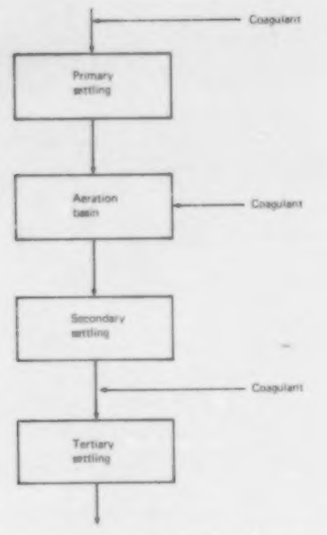


In these processes, chemicals called "coagulants"—such as aluminum sulfate (alum), lime, or ferric chloride—are added. These coagulants cause the solids in the wastewater to coagulate and clump together so as to settle out faster. The clumping together of solids is accelerated by slowly stirring (flocculating) the wastewater after the coagulants have been added. After flocculation, the wastewater enters a settling basin where the solids are settled out. The coagulation-flocculation process increases the rate at which the suspended solids settle. If the proper amount of coagulant is added, the coagulant reacts with the phosphorus in the wastewater to convert it to an insoluble form that can also be removed by settling, removing 90 percent of the phosphorus and suspended solids normally present in a secondary effluent. The land treatment process discussed later is another available means of phosphorus removal.



The coagulant does not necessarily have to be added in a process downstream of the secondary process. Some plants add the coagulant to the raw wastewater as it enters the plant and remove the resulting solids in the primary clarifier; others add the coagulant to the aeration tank of an activated-sludge plant, where it is mixed by the aeration process and the resulting floc is removed in the secondary clarifier; and others add the coagulant downstream.

In still another variation, the activated-sludge process is operated so as to take up as much phosphorus as possible in the activated-sludge particles. The phosphorus is then stripped in a digestion process from the activated sludge after it has settled and while it is being returned to the aeration tank, and the coagulant is applied to the highly concentrated phos-



ALTERNATIVE POINTS FOR COAGULANT ADDITION FOR PHOSPHORUS REMOVAL

phorus stream from the stripping operation. Adding coagulation to the raw wastewater has the advantage over tertiary addition of also removing some of the BOD from the secondary process, reducing the size of the secondary biological treatment units needed. Adding coagulant either to the raw wastewater or to the aeration basin allows removal of the chemical floc without the need for a separate tertiary settling basin. However, adding coagulant downstream of the secondary process with provision of a tertiary settling basin offers greater removal of suspended solids and improves overall system reliability by providing a means for removal of any solids that escape the secondary clarifier.

If lime is used as the coagulant, it causes an increase in the pH of the wastewater. "pH" is a measure of the acidity or alkalinity of the wastewater. A pH value of 7 is used to describe a perfectly neutral (neither alkaline nor acid) wastewater. The higher the pH, the more alkaline is the wastewater (pH = 14 is the maximum end of the scale). The lower the pH, the more acid is the wastewater (pH = 0 is the lower end of the scale). A bonus resulting from the use of high-pH lime coagulation is the removal of certain heavy metals that may be present at times in wastewater as a result of certain types of industrial wastewater discharges. Concentrations of antimony, chromium, cadmium, copper, iron, lead, manganese, nickel, silver, and zinc will be reduced more than 90 percent if present. High pH is also effective in killing a substantial number of viruses and bacteria.

The amount of coagulants required varies from locale to locale, depending on the characteristics of the wastewater being treated. Quantities may range from 375-3,000 pounds per million gallons. Usually, the higher end of the range is required for maximum removal of phosphorus, while the lower end may be adequate for just suspended solids removal. Tests must be conducted to determine the coagulant best suited for a given wastewater. Consideration must be given to the local costs of the alternative coagulants, sludge disposal, and the local availability of the chemicals.

In addition to the foregoing coagulants, synthetic organic chemicals called "polymers" are sometimes used in very small amounts (less than 10 pounds per million gallons) to increase further the settling rate of the solids. When used for this purpose, they are called "settling aids."

There are many plants now using coagulation for phosphorus removal, suspended solids removal, or both. Among these are Escanaba, Bay City, and Wyoming, Michigan; South Lake Tahoe and Orange County, California; Rochester, New York; Alexandria, Virginia; Rocky River, Cleveland, and Sandusky, Ohio; Palmetto and Tampa, Florida; Boulder, Colorado; Richardson, Texas; Piscataway, Maryland; and Michigan City, Indiana.

Advantages. Coagulation-sedimentation is a well-proven process that provides reliable removal of BOD and suspended solids. Process control is simple. When used downstream of secondary treatment, it improves the overall system reliability by providing a means to remove the excessive quantities of solids that may escape occasionally from the biological process. Coagulation-sedimentation also may provide substantial removals of heavy metals, bacteria, and viruses.

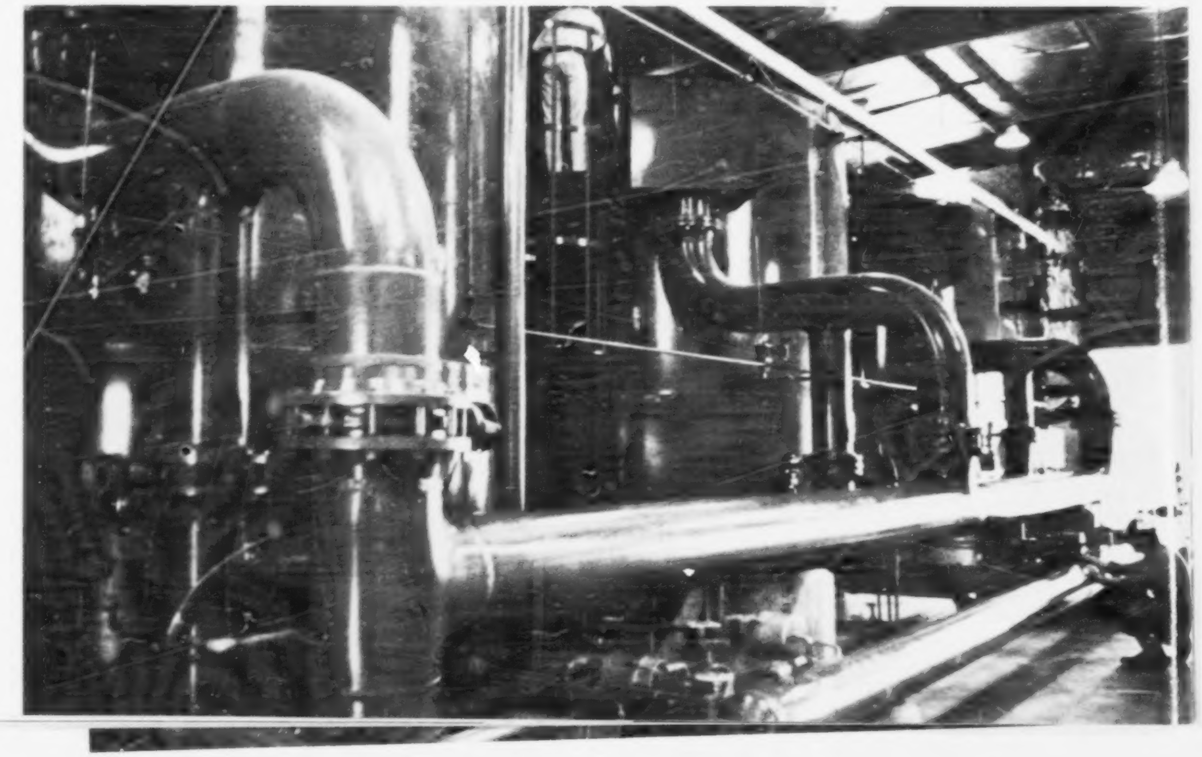
Disadvantages. Larger quantities of chemical sludge are usually generated. Although lime sludges may be recovered and reused, alum or ferric sludges cannot be. Also, the addition of chemicals may result in an addition of dissolved solids to the wastewater.

Energy Requirements. Power requirements for coagulant feeding equipment range from about 5-30 kwh per million gallons treated, depending on the coagulant used. Power requirements for separate rapid mixing, flocculation and sedimentation range from about 55-90 kwh per million gallons. Another significant consideration is the amount of energy required to manufacture the coagulants used in the treatment process. Typical energy requirements for the production of coagulants are: alum—2,000,000 Btu/ton; lime—5,500,000 Btu/ton; ferric chloride—10,000,000 Btu/ton; and polymer—3,000,000 Btu/ton.

Costs. The cost of phosphorus removal depends on the size of the treatment plant, type of chemicals used, and where these chemicals are added to the treatment scheme.

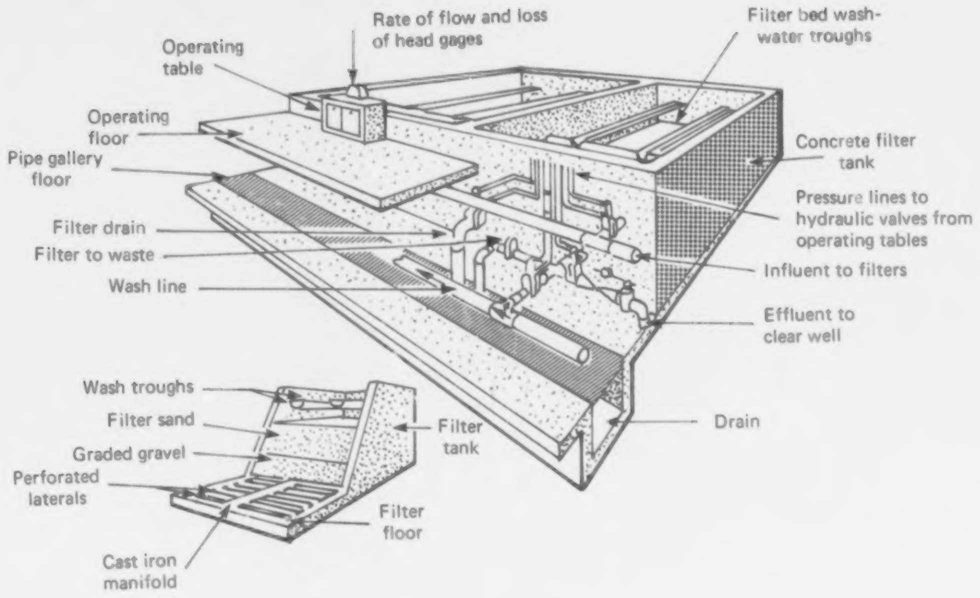
filtration

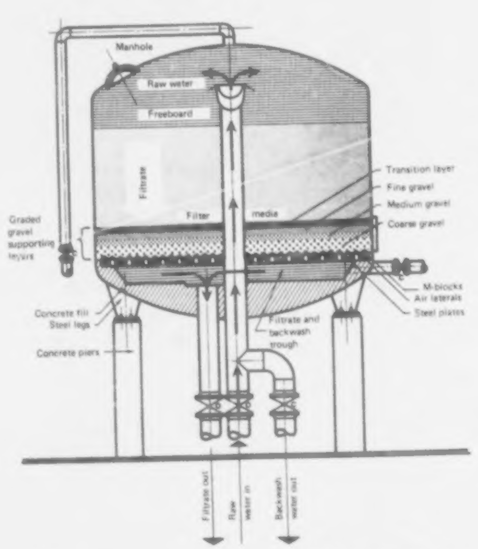
Filtration is the process of passing wastewater through a filtering medium, such as fine sand or coal, to remove suspended or colloidal matter. The goal of filtration in tertiary treatment is the removal of suspended solids from a secondary effluent or the effluent from the coagulation-sedimentation process. For example, the effluent from the tertiary coagulation and sedimentation typically will contain 3-5 mg/l suspended solids and 0.5-1 mg/l phosphorus. Efficient filtration of chemical effluent can reduce suspended solids to zero and phosphorus to 0.1 mg/l or less. Filtration of secondary effluents without chemical coagulation (plain filtration) is also used. Typically, plain filtration will reduce activated-sludge effluent suspended solids from 20-25 mg/l to 5-10 mg/l. Plain filtration is not effective on trickling-filter effluents, because the trickling-filter process is not as efficient in flocculating the microbes so that they are in a form readily removed by filtration.



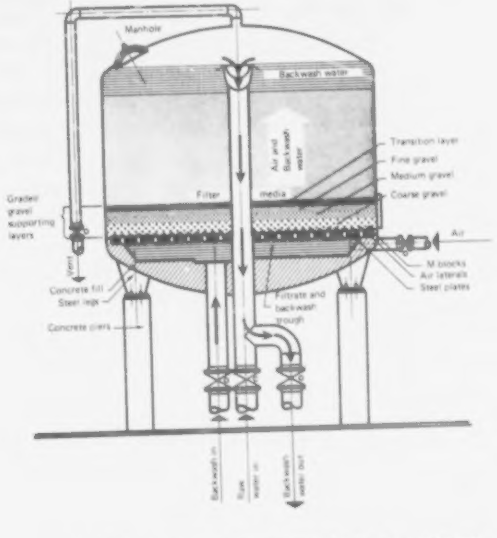
Filtration of wastewater is typically achieved by passing the wastewater through a granular bed 30-36 inches deep, composed of relatively small particles (less than 1.5 millimeter in size). Some filters use deeper beds and coarser materials to achieve similar results. Modern wastewater filters are usually made up of a mixture of two to three different materials or media (coal, sand, and garnet are commonly used) of varying sizes and specific gravities. These materials form a filter (called a multimedia filter), which is coarse at the upper surface and becomes uniformly finer with depth. Proper selection of filter media is extremely important in wastewater filtration, because the wastewater solids content is variable and may reach high levels if the processes upstream of the filtration process are not operated properly. Conventional filters such as those used widely in water treatment, made up of only one gradation of sand, may also be used in wastewater treatment. This type of filter normally requires more frequent backwashing or cleaning than the multimedia filters.

Wastewater is passed downward through the filter during its normal cycle of operation. Eventually, the filter becomes plugged with material removed from the wastewater, and is then cleaned by reversing the flow (called "backwashing"). The upward backwash rate is high enough that the media particles are suspended and the wastewater solids are washed from the bed. These backwash wastewaters (usually less than 5 percent of the wastewater flow treated) must be recycled to the wastewater treatment plant for processing. Filtration may be accomplished in open concrete structures by gravity flow, or in steel pressure vessels. The operation and control of the process may be readily automated.


Operating table
Rate of flow and loss of head gages
Filter bed wash-water troughs
Operating floor
Pipe gallery floor
Concrete filter tank
Pressure lines to hydraulic valves from operating tables
Filter drain
Filter to waste
Influent to filters
Wash line
Effluent to clear well
Wash troughs
Filter sand
Graded gravel
Perforated laterals
Filter tank
Drain
Filter floor
Cast iron manifold

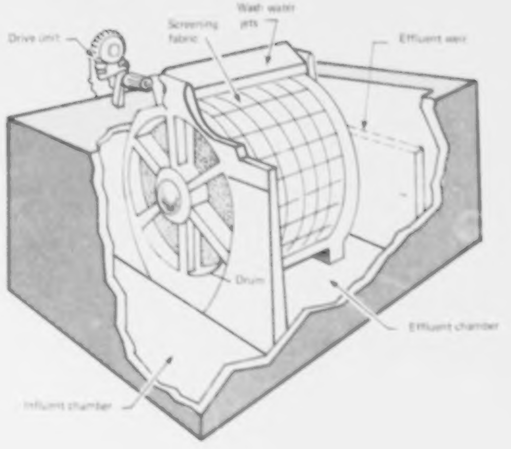

Manhole
Raw water
Freeboard
Filtrate
Filter
media
Transition layer
Fine gravel
Medium gravel
Coarse gravel
Graded gravel supporting layers
M-blocks
Air laterals
Steel plates
Concrete fill
Steel legs
Filtrate and backwash trough
Concrete piers
Filtrate out
Raw water in
Backwash water out

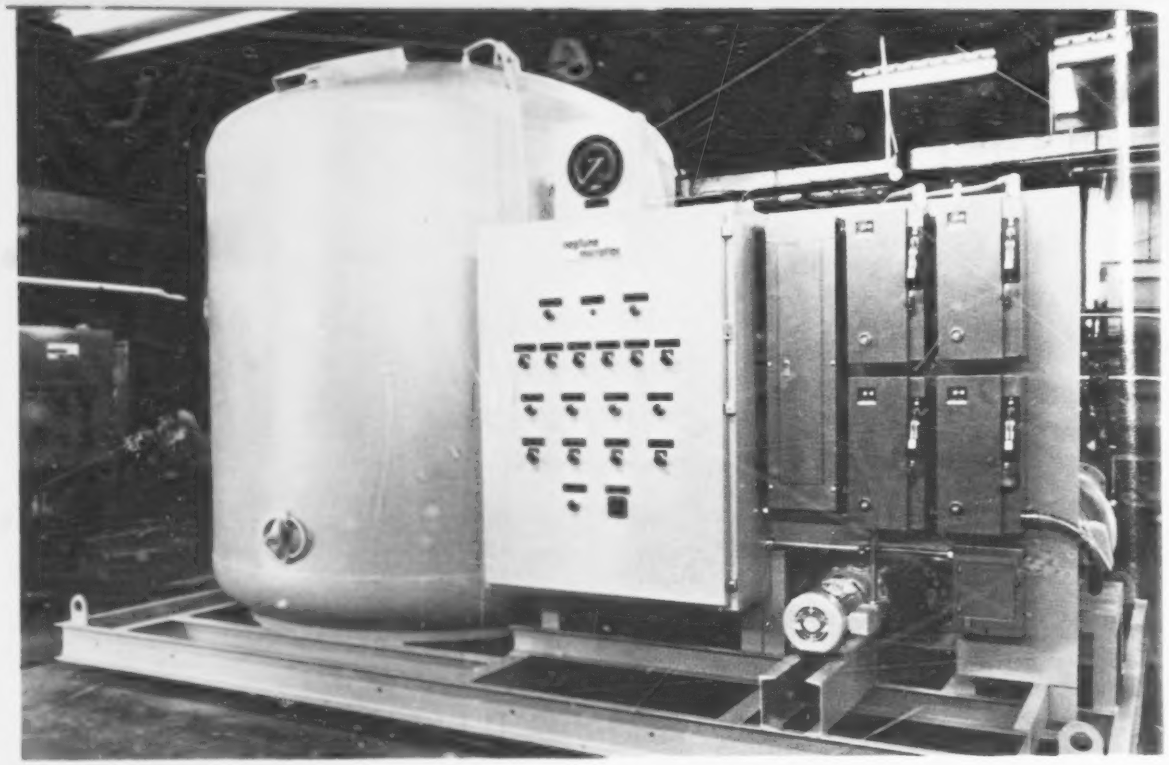
PRESSURE FILTER—FILTER CYCLE SCHEMATIC


Manhole
Backwash water
Air and Backwash water
Transition layer
Fine gravel
Medium gravel
Coarse gravel
Filter
media
Graded gravel supporting layers
Air
Vent
M-blocks
Air laterals
Steel plates
Concrete fill
Steel legs
Filtrate and backwash trough
Concrete piers
Backwash in
Raw water in
Backwash water out

PRESSURE FILTER—BACKWASH CYCLE SCHEMATIC

TYPICAL MICROSCREEN UNIT


Drive unit
Screening fabric
Wash water jets
Effluent weir
Drum
Effluent chamber
Influent chamber


neptune microfloc

The use of multimedia filters in tertiary wastewater treatment applications is well established and successful. Illustrative wastewater installations include Louisville, Kentucky; Lemont and Hatfield Township, Pennsylvania; Aurora and Colorado Springs, Colorado; Benseville and Barrington, Illinois; Bedford Heights and Cleveland, Ohio; South Lake Tahoe, Orange County, Vallejo, and Ventura, California; Beaverton, Oregon; Piscataway, Maryland; Dallas, Texas; and Pontiac, Michigan.

Microscreening is another system used for filtration. Microscreens are mechanical filters that consist of a horizontally mounted drum, whose cylindrical surface is made up of a special metallic filter fabric. The drum rotates slowly in a tank with two compartments so that

water enters the drum from one end and flows out through the filtering fabric. The drum is usually submerged to approximately two-thirds of its depth. The solids are retained on the inside of the rotating screen, which has very fine openings of 23-60 microns, and are washed from the fabric through a row of jets fitted on top of the machine. The wastewater containing the solids flushed from the screen is collected in a hopper or trough inside the drum for return to the secondary plant. Microscreens used in plain filtration applications can reduce activated-sludge-effluent suspended solids from 20-25 mg/l to 6-10 mg/l. Microscreens have an advantage over granular filters in that they operate continuously without the need for a separate backwashing cycle. They have the disadvantage of being more sensitive to variations in the incoming suspended solid concentrations, and they are not used for removal of chemical floc. The largest U.S. installation of microscreening in a wastewater system is at the Chicago Sanitary District's Northside plant, with a design capacity of 15 mgd. Microscreening systems have been used at Akron, Ohio (3 mgd); Franklin Township (4 mgd), Hempfield Township (6 mgd) and Lionville, Pennsylvania (0.75 mgd); and Jackson Township, New Jersey (0.1 mgd).

Advantages. Effluent filtration provides a means of controlling the suspended solids content of a secondary effluent and providing added removals of phosphorus and suspended solids from the coagulation-sedimentation process. This positive control improves the overall reliability of treatment as well as providing a higher degree of treatment. It is a well-proven process, is readily automated, requires little operator attention, and requires little space.

Disadvantages. The process generates a backwash waste stream, which, although small in volume, must be recycled to the wastewater plant for processing.

Energy Requirements. The power consumption for filtration and backwashing is typically about 60 kwh per million gallons for gravity filters and about 80 kwh for pressure filters.

Space Requirements. The process and related auxiliary systems require 300-500 square feet per mgd of capacity.

Costs. The costs may range from 21 cents per 1,000 gallons ($2.20 per month per home) at 1 mgd to less than 5 cents per 1,000 gallons (55 cents per month per home) at 10 mgd.

carbon adsorption

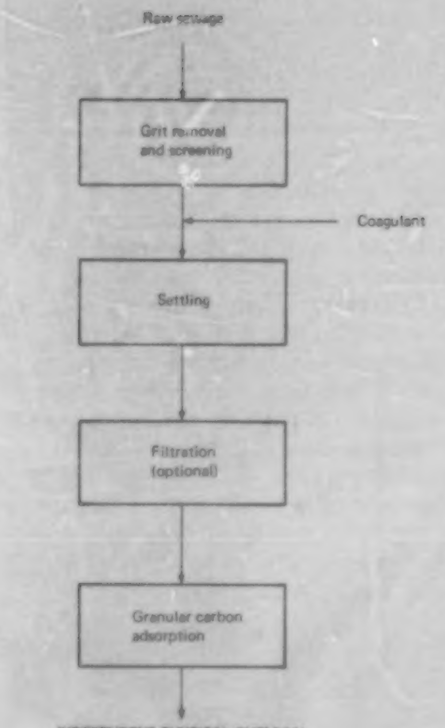
Even after secondary treatment, coagulation, sedimentation, and filtration, the soluble organic materials that are resistant to biological breakdown will persist in the effluent. The persistent materials are often referred to as "refractory organics," and are responsible for the color found in secondary effluent. Secondary effluent COD values are often 30-60 mg/l. The most practical available method for removing these materials is the use of activated carbon. Activated carbon removes organic contaminants from water by adsorption, which is the attraction and accumulation of one substance on the surface of another. The amount of carbon surface area available is the most important factor, because adsorption is a surface phenomenon. The activation of carbon in its manufacture produces many pores within the particles. It is the vast areas of the walls within these pores that account for most of the total surface area of the carbon that makes it so effective in removing organics. After the capacity of the carbon for adsorption has been exhausted, it can be restored by heating the carbon in a furnace at a temperature sufficiently high to drive off the adsorbed organics. Keeping oxygen at very low levels in the furnace prevents the carbon from burning. The organics are passed through an afterburner to prevent air pollution. In small plants where the cost of an onsite regeneration furnace cannot be justified, it may be attractive to ship the spent carbon to a central regeneration facility for processing.

Activated carbon used for wastewater treatment may be either in a granular form (about 0.8 millimeter in diameter, the size of a fairly coarse sand) or in a powdered form. The carbon in powdered form is mixed with the wastewater for several minutes to allow adsorption to occur and then removed by settling—usually with the assistance of a coagulant. The powdered form is more difficult to handle (dust problems) and more difficult to regenerate than the granular form. Regeneration is essential to favorable economics in wastewater treatment because of the large quantities of carbon needed. For these reasons, powdered carbon has not had as widespread use in wastewater treatment as has granular carbon. However, the powdered form requires much less capital investment than the granular form. Work is continuing on the development of improved methods for regenerating powdered carbon that may permit realization of its potential benefits.

Granular carbon adsorption is achieved by passing the wastewater through beds of the carbon that may resemble a gravity filter or that may be housed in deep columns (20-25 feet). These carbon beds usually provide 20-40 minutes contact between the carbon and the wastewater.

The degree of treatment provided before carbon adsorption can be varied, depending on the desired final effluent quality. Where very high degrees of treatment are required, secondary treatment, coagulation-sedimentation, and filtration usually precede carbon treatment. Some organic materials (sugars, for example) are very difficult to remove by adsorption but are readily removed by activated sludge. Thus, using biological treatment before carbon adsorption insures the maximum removal of organics. The use of coagulation-sedimentation and filtration as further pretreatment removes small suspended particles that could plug the small pores in the carbon particles, reducing carbon efficiency. By combining these processes, a colorless, odorless effluent, free of bacteria and viruses, with a BOD of less than 1 mg/l and a COD of less than 10 mg/l, can be produced. To put this COD in perspective, several drinking water supplies in the United States have a COD of more than 10 mg/l. The water quality is so good that it is suitable for many reuse purposes. A utility district at South Lake Tahoe, California, uses the above process sequence and has used its effluent to create a recreational lake that supports an excellent trout fishery and that has been approved for swimming by health authorities. Another plant at Orange County, California, uses the carbon-treated effluent to recharge its ground water supply. A plant at Windhoek, South Africa, recycles its carbon-treated wastewater directly to the drinking water system.

Among the plants in design or operation using activated carbon for treatment of secondary effluent are: Arlington (30 mgd), Occoquan Sewage Authority (11 mgd), and Fairfax County (36 mgd), Virginia; Colorado Springs, Colorado (3 mgd); Dallas, Texas (100 mgd); Los Angeles (5 mgd), Orange County (15 mgd), and South Lake Tahoe (7.5 mgd), California; Piscataway (5 mgd), Maryland; and St. Charles, Missouri (5.5 mgd).



INDEPENDENT PHYSICAL-CHEMICAL TREATMENT

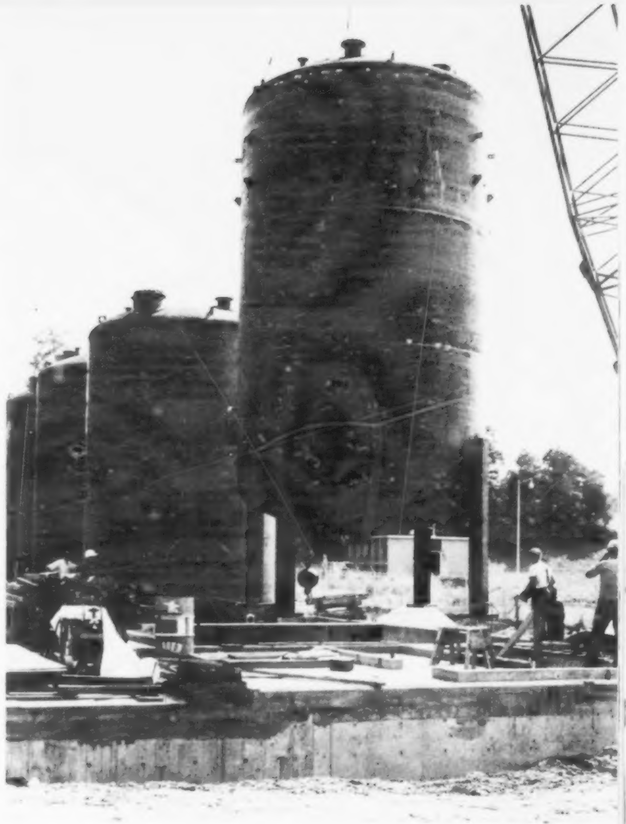
Another approach to using the ability of carbon to remove organics is called "independent physical-chemical treatment" (IPC). In this approach, biological secondary processes are eliminated altogether, and the carbon is the sole means of soluble organics removal. In such a system, the raw wastewater is usually coagulated and settled (and sometimes filtered) before it is passed through the carbon system. Such a system provides a degree of treatment better than biological secondary but not as good as that of biological secondary followed by carbon adsorption. The IPC approach reduces the space requirements of a conventional biological plant by a factor of about 4, and the system is not affected by any toxic materials that could upset a biological process (and, in fact, removes most toxins). The approach is useful in meeting treatment requirements that are intermediate between secondary and the most rigid AWT standards, or in cases where space is very limited or troublesome industrial toxins are present. The level of treatment is higher than biological secondary, as are the overall costs in most cases.

There are several IPC plants in design or operation, including Cortland (10 mgd), LeRoy (1 mgd), and Niagara Falls (48 mgd), New York; Cleveland Westerly (50 mgd) and Rocky River (10 mgd), Ohio; Fitchburg, Massachusetts (15 mgd); Garland, Texas (30 mgd); Owosso, Michigan (6 mgd); Rosemount, Minnesota (0.6 mgd); and Vallejo, California (13 mgd).

Advantages. Carbon adsorption removes organic materials that cannot be removed by biological secondary processes. The operation can tolerate wide variations in flow or wastewater quality and requires little operator attention. The process requires little space.

Disadvantages. The economics of the process are improved markedly by use of carbon regeneration and recycling, but regeneration equipment is not readily adaptable to very small plants (less than 3 mgd). The regeneration process requires careful operator control.

Energy Requirements. Carbon adsorption and regeneration typically consume about 120 kwh electricity and about 3.3 million Btu fuel per million gallons. In addition,the energy required to manufacture activated carbon to makeup for carbon lost in regeneration can be from 1,000,000-5,000,000 Btu per million gallons.



Space Requirements. The carbon process typically requires 300-500 square feet per mgd of capacity.

Costs. At 10 mgd, the costs of carbon adsorption and regeneration are about 17-22 cents per 1,000 gallons ($1.80-$2.30 per month per home), while at 1 mgd, if carbon regeneration is not practiced, they may be as high as 42 cents per 1,000 gallons ($4.10 per month per home).

nitrogen control

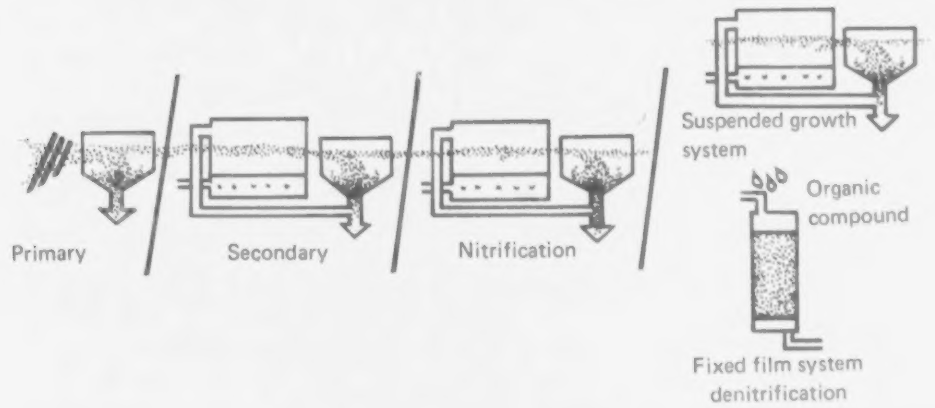
Nitrogen in its many forms has long played a fundamental role in the aquatic environment. It is now apparent that ecological imbalances in the natural environment have been caused, in part, by the excessive discharges of nitrogeneous materials to natural waterways. In certain forms, nitrogen is one of the major nutrients supporting blooms of green and blue-green algae in surface waters. Nitrogen not only has nutrient value, but, in its various forms, can represent as much as 70 percent of the total oxygen demand of conventionally treated municipal wastewater.

During conventional biological wastewater treatment, almost all the nitrogen contained in the wastewater is converted into ammonia nitrogen. Although ammonia has very little toxicity to humans, treated wastewater effluent containing ammonia has several undesirable features.

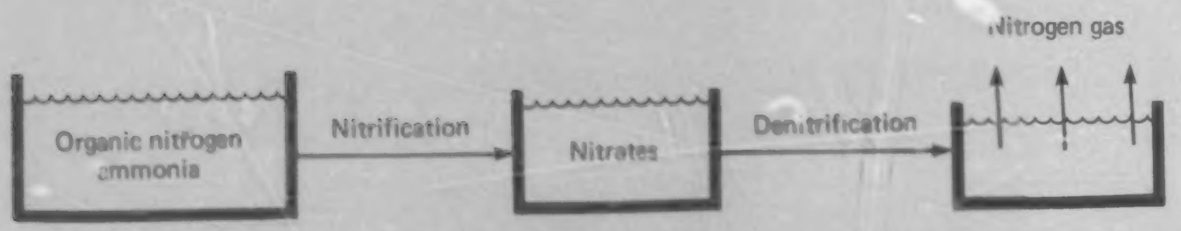
- Ammonia consumes dissolved oxygen in the receiving water.
- Ammonia can be toxic to fish life.
- Ammonia is corrosive to copper fittings.
- Ammonia increases the amount of chlorine required for disinfection.

Ammonia nitrogen can be reduced in concentration or removed from wastewater by several processes. These processes can be divided into two broad categories: biological methods and physical-chemical methods. The physical-chemical category can be further divided into the following processes.

- Ammonia stripping
- Selective ion exchange
- Breakpoint chlorination



Biological Nitrification-Denitrification. This process is the biological conversion of nitrogenous matter into nitrates (nitrification), followed by the anaerobic biological conversion of the nitrates to nitrogen gas (denitrification). The process is based on the principle that the nitrogen compounds found in raw sewage may be converted to the nitrate form in a properly designed secondary biological process (the nitrification process). These nitrates may then be removed by further treatment in the absence of oxygen. Under these anaerobic conditions, the nitrogen is released as nitrogen gas (the denitri-



SCHEMATIC OF BIOLOGICAL NITRIFICATION-DENITRIFICATION PROCESS

fication process). Because nearly 80 percent of the atmosphere consists of nitrogen, there is no air pollution associated with the release of nitrogen from the wastewater to the atmosphere.

In some cases, carrying out only the nitrification portion of the process may be adequate. Nitrification is accomplished by providing oxygen in the amount required in the biochemical reaction to convert ammonia nitrogen to nitrate nitrogen, or roughly 4.5 pounds of oxygen per pound of ammonia nitrogen in the wastewater.

There are several alternative approaches to biological nitrogen removal. The most reliable performance has been found to occur when the first step of treatment is an activated-sludge step, which oxidized most of the raw wastewater BOD. The nitrification step can then be accomplished in a suspended growth system similar to the activated-sludge process, in a fixed-film system consisting of a trickling-filter-like column of stones or synthetic media, or with rotating biological contactors. The organisms that carry out the nitrifying step are very slow growing, and, if they are lost from the suspended growth system because of poor settling characteristics or for other reasons, process performance may suffer for many weeks until an adequate population of nitrifiers can be established again. Thus, the fixed-film system for nitrification offers an advantage in that it provides greater assurance of retention of the nitrifying organisms.

When the effluent from a wastewater treatment plant is discharged to a receiving water with a significant flow, such as a river, nitrate nitrogen may not affect it adversely. In fact, a nitrified effluent free of substantial quantities of ammonia can offer several advantages:

- Nitrate nitrogen provides oxygen to sludge beds and prevents the formation of septic odors.

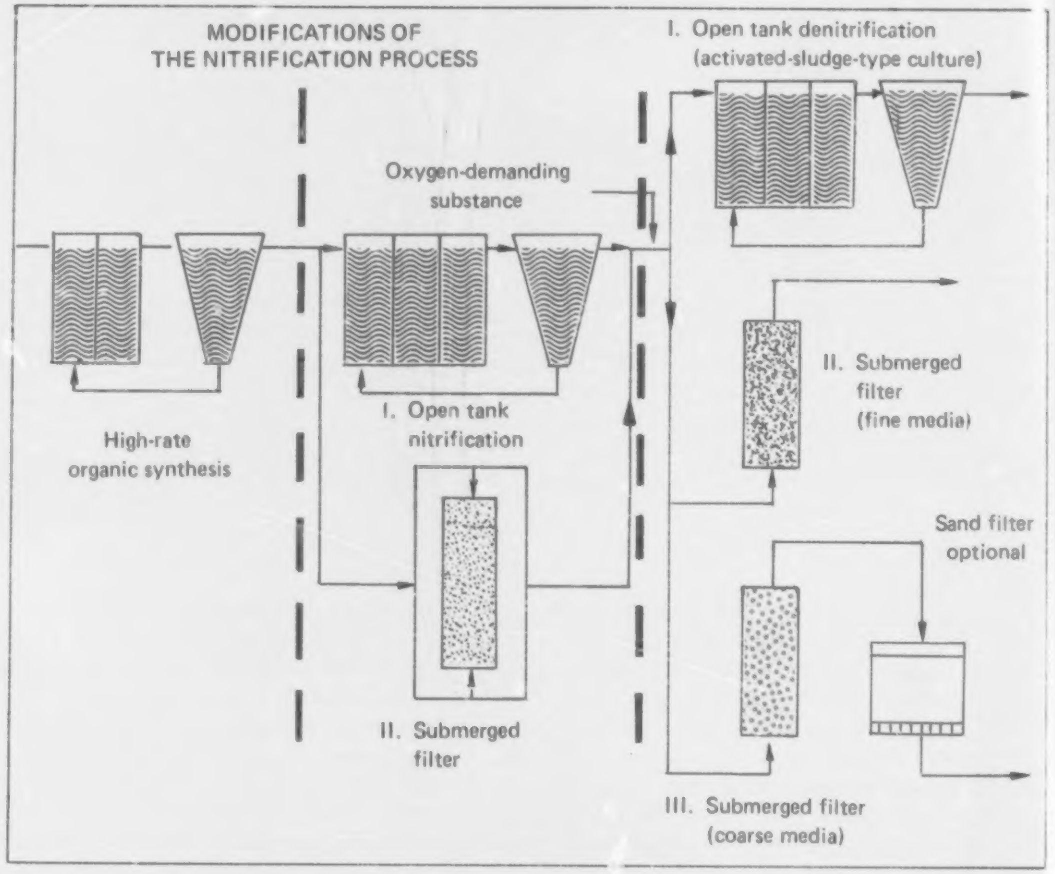
- Nitrified effluents are more efficiently disinfected by chlorine treatment.
- A nitrified effluent reduces the oxygen demand on the receiving waters.

The deciding factor in determining whether the discharge of a nitrified effluent to a free-flowing receiving water is acceptable is the level of nitrate nitrogen it contains. If the level is too high, then further action is necessary to control the nitrogen content of the effluent. This is also the case when treated wastewater is discharged to relatively still bodies of water, such as lakes, reservoirs, and estuaries. In these cases, even a highly nitrified effluent can have harmful effects, such as fostering algal blooms.

If a nitrified effluent is determined unacceptable, then nitrogen removal by downstream use of the denitrification process is required.

The denitrification step can be accomplished either in an anaerobic activated-sludge system (suspended growth system) or in a columnar system (fixed-film system). The high degree of biological treatment upstream of the denitrification process leaves little oxygen-demanding material in the wastewater by the time it reaches denitrification. The desired nitrate reduction will occur only as a result of oxygen demand being exerted in the absence of oxygen in the wastewater. If denitrification is to be practical, an oxygen-demand source must be added to reduce the nitrates quickly. The most common method of supplying the needed oxygen demand is to add methanol in the denitrification process.

The efficiency of biological nitrification-denitrification is usually 80-90 percent nitrogen removal. The process is in use or planned for use at El Lago, Texas (0.5 mgd); Tampa (50 mgd) and Orlando (12 mgd), Florida; Hobbs, New Mexico (5 mgd); Salt Creek (50 mgd) and


MODIFICATIONS OF
THE NITRIFICATION PROCESS
High-rate
organic synthesis
Oxygen-demanding
substance
I. Open tank
nitrification
II. Submerged
filter
I. Open tank denitrification
(activated-sludge-type culture)
II. Submerged
filter
(fine media)
Sand filter
optional
III. Submerged filter
(coarse media)

Waukegan (30 mgd), Illinois; and Madison, Ohio (6 mgd). Nitrification (without denitrification) is planned or in use at Washington, D.C. (309 mgd); Madison, Wisconsin (30 mgd); Flint (20 mgd), Jackson (17 mgd) and Benton Harbor (13 mgd), Michigan; and Waukegan (20 mgd), Highland Park (18 mgd), and Gurnee (17 mgd), Illinois.

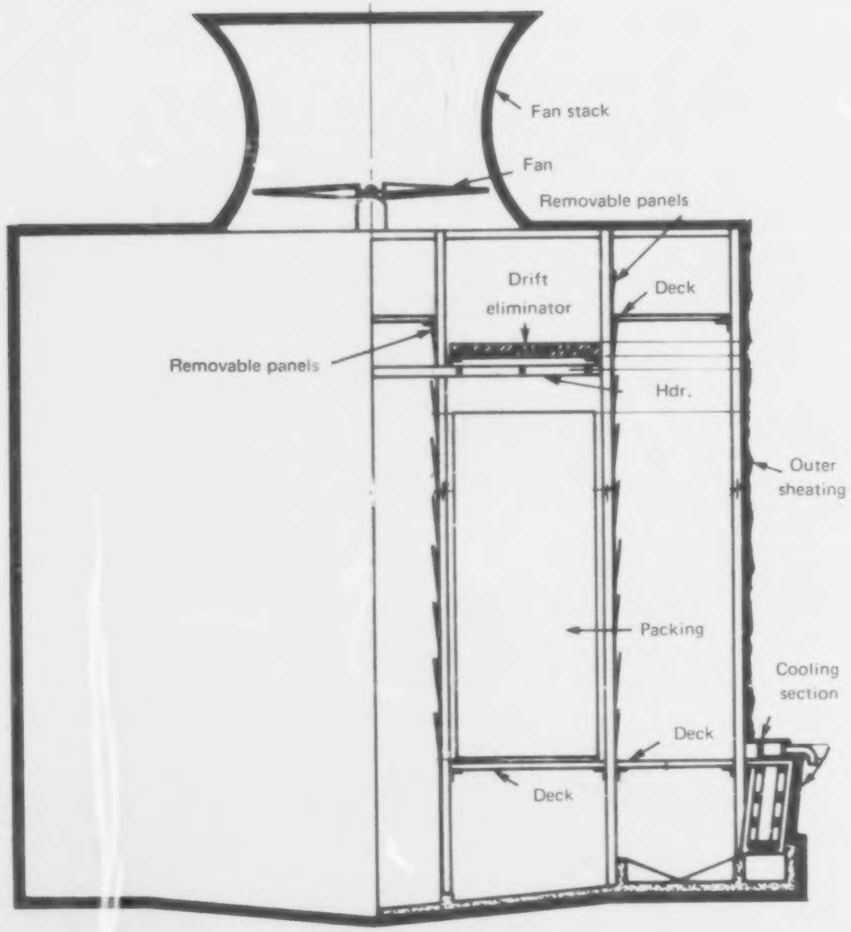
Advantages. The biological processes involved are similar to those used in the past for secondary treatment, both in design and operation. The process generates no significant added sludge for disposal, nor does it have any objectionable side effects on air or water quality.

Disadvantages. The process requires more space than other methods of nitrogen removal. The process can be upset by toxic materials. The loss of microbes from any of the three biological processes used in series, whether from toxins, equipment failure, or operator error, can disrupt performance for many days.

Engergy Requirements. Nitrification consumes substantial added power—about 470 kwh per million gallons for a suspended growth system or about 370 kwh for a fixed-film system. The denitrification process, using a suspended growth system, requires another 260 kwh per million gallons. In addition, the energy required to manufacture the amount of methenol typically used in denitrification is about 9,000,000 Btu per million gallons.

Space Requirements. The space requirements depend on the configuration of nitrification and denitrification units selected, but will typically be 0.3-0.6 acre per mgd capacity.

Costs. The costs for nitrification-denitrification may typically range from 42 cents per 1,000 gallons at 1 mgd ($4.40 per month per home) to 20 cents per 1,000 gallons at 10 mgd ($2.10 per month per home).



AMMONIA STRIPPING TOWER

Ammonia Stripping. This process removes gaseous ammonia from water by agitating the water-gas mixture in the presence of air. In practice, the process is based on the principle that nitrogen in the form of ammonium ions in secondary effluent can be converted to ammonia gas by raising the pH to high values. The gaseous ammonia can then be released by passing the high-pH effluent through a stripping tower where the agitation of the water in the presence of a large air flow through the tower releases the ammonia. The use of lime in coagulation-sedimentation permits simultaneous coagulation for suspended solids and phosphorus removal and the necessary upward adjustment of pH for the stripping process.

The three basic steps in ammonia stripping are (1) raising the pH of the water to form ammonia gas, generally with the lime used for phosphorus removal, (2) cascading the water down through a stripping tower to release the ammonia gas, and (3) circulating large quantities of air through the tower to carry the ammonia gas out of the system. The towers used for ammonia stripping closely resemble conventional cooling towers. The concentration of ammonia in the offgas from the tower is very low—well below odor levels—and does not cause air pollution problems.

The major process limitation is the effect of temperature on efficiency. As the air temperature drops, efficiency also drops. For example, stripping removes about 95 percent of the ammonia in warm weather (70° F air temperature) but only about 75 percent of the ammonia when the temperature falls to 40° F. The process becomes inoperable as a result of freezing problems within the stripping tower when the air temperature falls very far below freezing.

Ammonia stripping has been used at South Lake Tahoe (7.5 mgd) and Orange County (15 mgd), California; and Bucks County, Pennsylvania (7.0 mgd).

Advantages. The process offers the lowest cost method of nitrogen removal now available. It is also the simplest to operate, and its simplicity insures reliability. It requires little space.

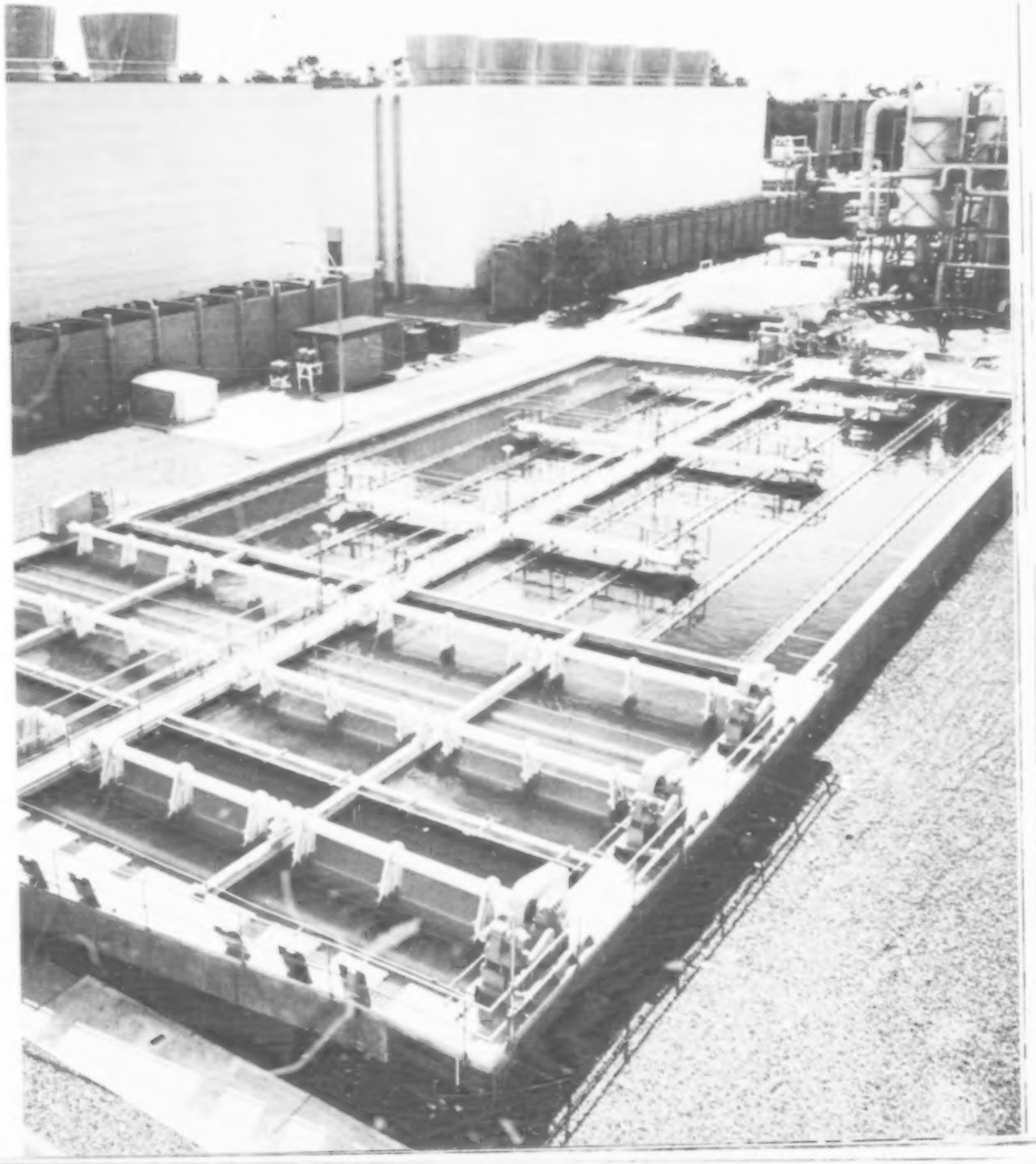
Disadvantages. Cold weather adversely affects performance, and prolonged periods of freezing weather render the process inoperable. Deposits resulting from the upstream lime treatment can occur within the tower, and provisions for controlling or removing the deposits must be made.

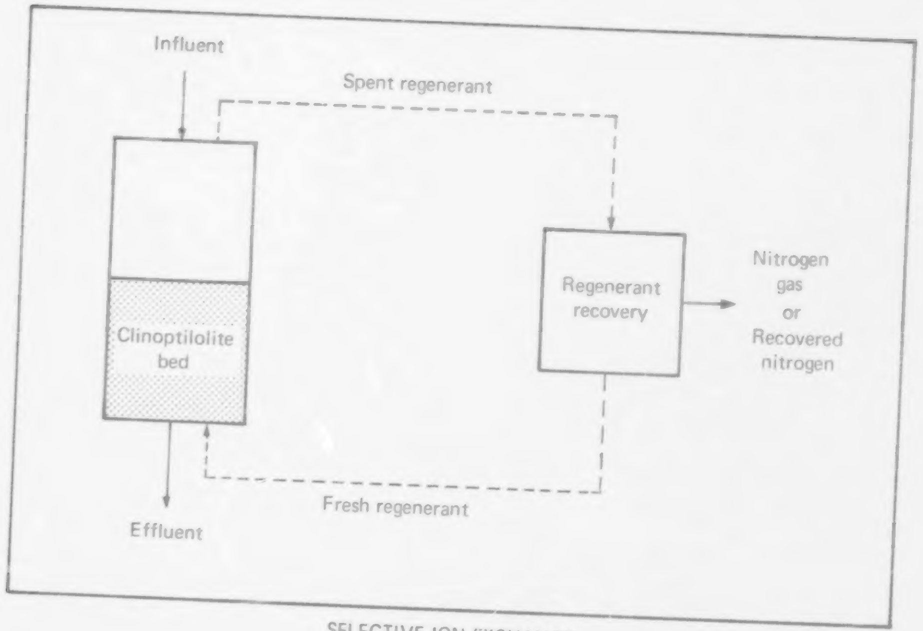
Energy Requirements. Power requirements are about 1,700 kwh per million gallons.

Space Requirements. Total space requirements are usually less than 700 square feet per mgd of capacity.

Costs. Costs range from 14 cents per 1,000 gallons at 1 mgd ($1.50 per month per home) to 10.5 cents per 1,000 gallons at 10 mgd ($1.10 per month per home).

Selective Ion Exchange. By this process, ammonium ions in solution are exchanged for sodium or calcium ions displaced from an insoluble exchange material. The process operation resembles that of a water softener, except that the material being removed is ammonium-nitrogen rather than water hardness. Both are ion-exchange processes, where the water is passed through a bed of ion-exchange material that has the ability to remove certain constituents in exchange for a constituent of the exchange material. The selective ion-exchange process derives its name from the use of an





SELECTIVE ION EXCHANGE

ion-exchange material that selectively removes ammonium. The ion-exchange material is a naturally occurring zeolite called "clinoptilolite." Ammonium is removed by passing the wastewater through a bed of clinoptilolite until the capacity of the clinoptilolite has been used to the point that ammonia begins to leak through the bed. At this point, the clinoptilolite must be regenerated so that its capacity to remove ammonia is restored.

The clinoptilolite is then regenerated by passing concentrated salt solutions through the exchange bed. The ammonium-laden regenerant volume is about 5-6 percent of the throughput volume treated before regeneration. If the ammonium is removed from the regenerant, the regenerant can be reused. There are no regenerant brines to dispose of, avoiding a major problem of conventional, nonselective exchange resins. Several techniques are available for removal of ammonium from the regenerant, some of which release the ammonium as nitrogen gas. Others recover the nitrogen in reusable forms such as ammonium sulfate or aqueous ammonia.

The process is very efficient and can remove 95-97 percent of the ammonium nitrogen. The process is in use at Rosemount, Minnesota (0.6 mgd); the Upper Occoquan Sewage Authority, Virginia (10.9 mgd); and the Tahoe Truckee Sanitation Agency, California (5 mgd).

Advantages. Efficiency for nitrogen removal is very high, is readily controllable, and is not sensitive to temperature variations. The process lends itself well to the eventual recovery of the nitrogen in a form that can be used as a fertilizer. Space requirements are low.

Disadvantages. Equipment and operation are relatively complex and the capital costs are high.

Energy Requirements. Power consumption depends primarily on how the regenerant recovery process is handled, but will be about 250 kwh per million gallons in most cases.

Space Requirements. The space required for the ion-exchange beds and the related regenerant recovery system is usually less than 1,000 square feet per mgd.

Costs. The costs may range from about 46 cents per 1,000 gallons at 1 mgd ($4.85 per month per home) to 28 cents per 1,000 gallons at 10 mgd ($2.95 per month per home).

Breakpoint Chlorination. In this process, chlorine is added to wastewater in such amounts that the chlorine demand is satisfied so that further addition of chlorine results in a directly proportional chlorine residual. It is used for nitrogen removal because chlorine, when added to wastewater containing ammonium nitrogen, reacts to form compounds that, if enough chlorine is added, eventually are converted to nitrogen gas. To achieve the conversion, about 10 mg/l of chlorine must be added per mg/l of ammonia nitrogen in the wastewater. A typical secondary effluent ammonia concentration of 20 mg/l requires the use of about 1,700 pounds of chlorine per million gallons treated—about 40 or 50 times more than normally used in a wastewater plant for disinfection only.

The facilities required for the process are simple. Wastewater (after secondary or tertiary treatment) flows into a mixing chamber where the chlorine is added and thorough mixing is provided. Because the large amount of chlorine used has an acidic effect on the wastewater, alkaline chemicals (such as lime) may be added to the same chamber to offset this effect. The nitrogen gas formed by the reactions is released to the atmosphere. The process can achieve 99+ percent removal of the ammonium nitrogen. The chemical additions are monitored and controlled by a computer system, providing automated operation. The amounts of chlorine used provide very effective disinfection as well as nitrogen removal. Because the process is just as effective in removing 1 mg/l as 20 mg/l of ammonium, it is used frequently as a polishing step downstream of other nitrogen removal processes. The low capital cost of the breakpoint process makes it attractive for this purpose. The process is used or planned for use at Cortland, New York (10 mgd); Owosso, Michigan (6 mgd); Arlington County, Virginia (30 mgd); and Orange County (15 mgd) and South Lake Tahoe (7.5 mgd), California.

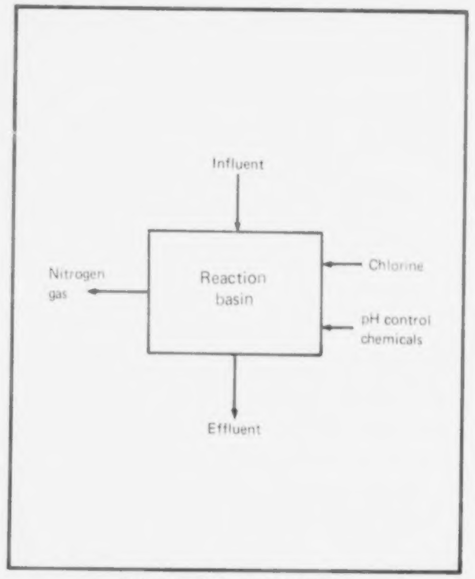
Advantages. The principal advantages of breakpoint chlorination are its high efficiency, small space requirements, low capital costs, assurance of disinfection, and the conversion of ammonium to elemental nitrogen that presents no disposal problem.

Disadvantages. The chlorine added results in an increase in the chloride content of the wastewater. If the effluent is not discharged to a coastal estuary or mixed with large quantities of freshwater, this increase may be significant if there are downstream water supplies. The process requires large quantities of chlorine.

Energy Requirements. The manufacture of the amount of chlorine used for breakpoint chlorination of 20 mg/l of ammonia requires about 35,000,000 Btu per million gallons.

Space Requirements. Total space requirements for the mixing chamber and related chemical feed and storage are typically less than 500 square feet per mgd capacity.

Costs. The costs primarily depend on the price of chlorine and the quantity of ammonium to be removed, with little economy of scale in the 1-10 mgd capacity range. Costs may range from 15-20 cents per 1,000 gallons ($1.60-$2.15 per month per home) for typical wastewaters with 20 mg/l of ammonium.



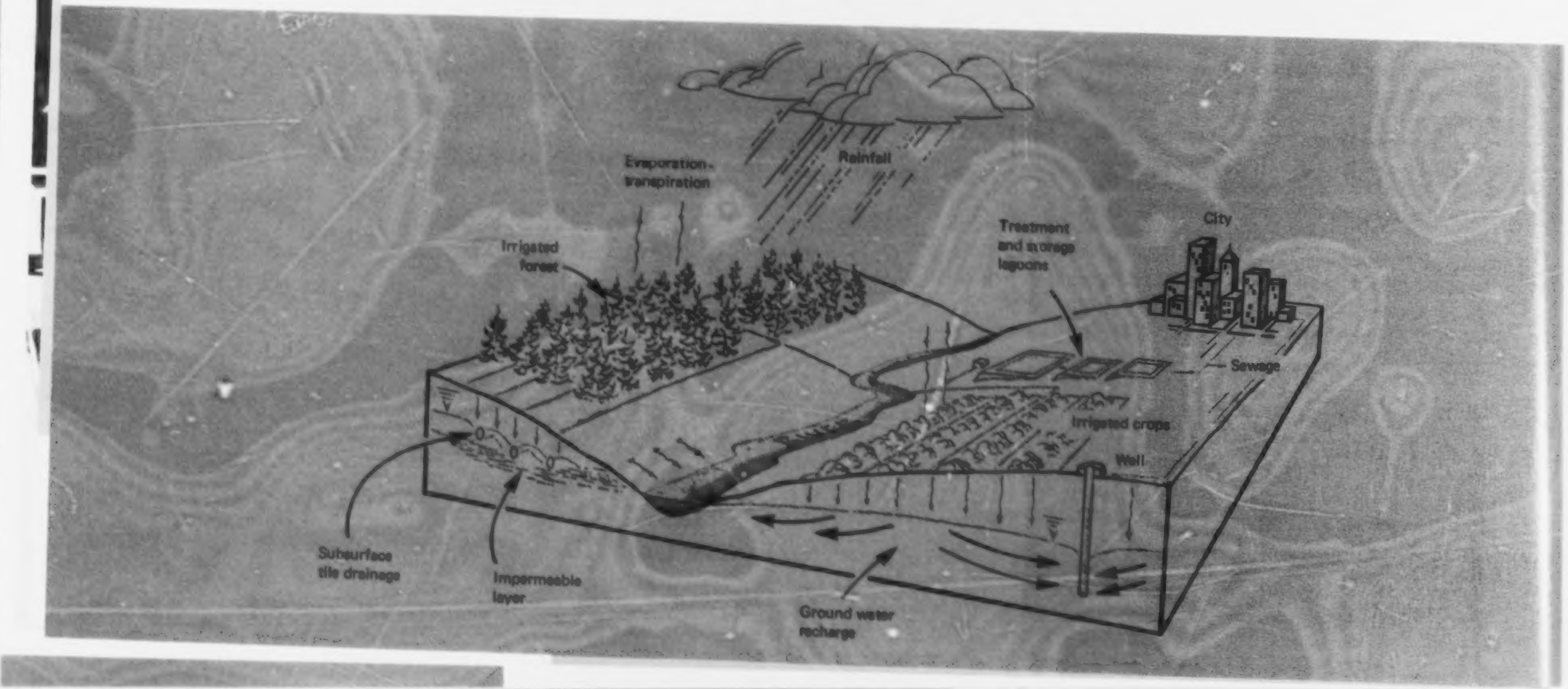
BREAKPOINT CHLORINATION

land treatment

An alternative to the previously discussed processes for producing an extremely high-quality effluent is offered by an approach called "land treatment." Land treatment is the application of effluents, usually following secondary treatment on the land by one of the several available conventional irrigation methods. This approach uses wastewater, and often the nutrients it contains, as a resource rather than considering it as a disposal problem. Treatment is provided by natural processes as the effluent moves through the natural filter provided by the soil, plants, and related ecosystem. Part of the wastewater is lost by evapotranspiration, while the remainder returns to the hydrologic cycle through overland flow or the ground water system. Most of the ground water eventually returns, directly or indirectly, to the surface water system.

Land treatment of wastewaters can provide moisture and nutrients necessary for crop growth. In semiarid areas, insufficient moisture for peak crop growth and limited water supplies make water especially valuable. The primary nutrients (nitrogen, phosphorus, and potassium) are reduced only slightly in conventional secondary treatment processes, so that most of these elements are still present in secondary effluent. Soil nutrients are consumed each year by crop removal and lost by soil erosion. Fertilizer supply is highly dependent on energy input, and recently has increased significantly in price. Recycling wastes to the land so that the nutrient cycle can be completed and soil fertility maintained is an alternative that should be given serious consideration.

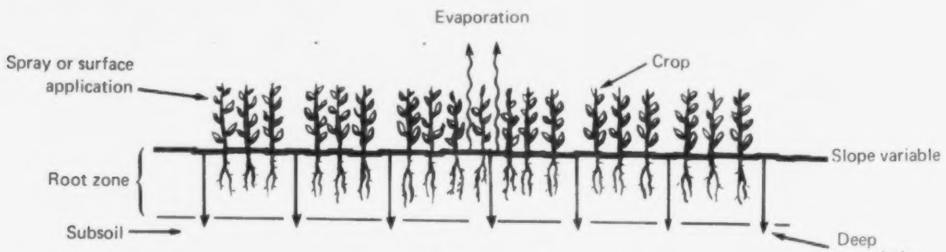
Land application is the oldest method used for treatment and disposal of wastes, with use by cities recorded for more than 400 years. Several major cities, including Berlin, Melbourne, and Paris, have used "sewage farms" for at least 60 years for waste treatment and disposal. About 600 communities in the United States reuse municipal wastewater treatment plant effluent in surface irrigation systems, mostly in arid or semiarid areas.



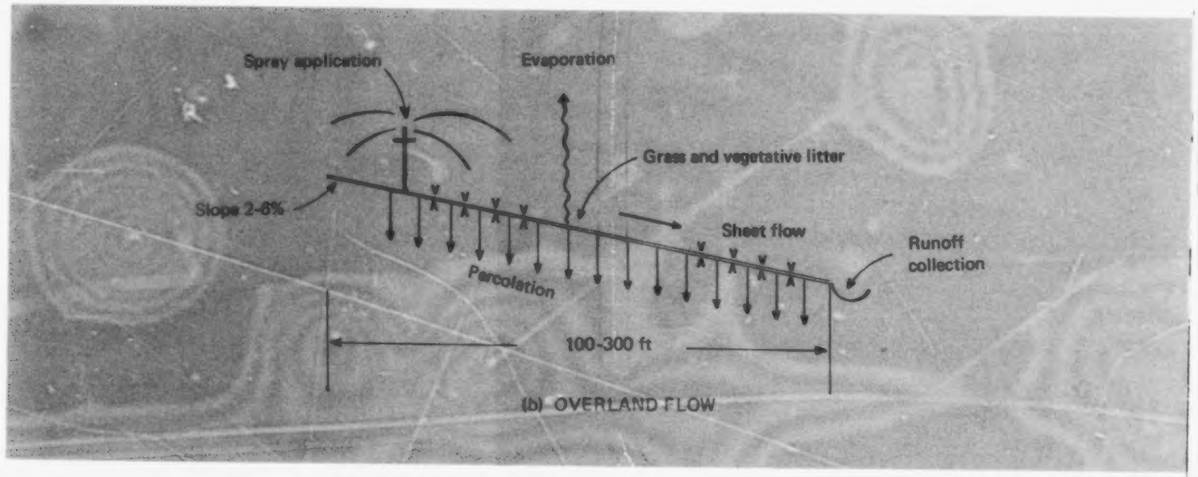
Land treatment systems use one of the three basic approaches:

- Irrigation
- Overland flow
- Infiltration-percolation

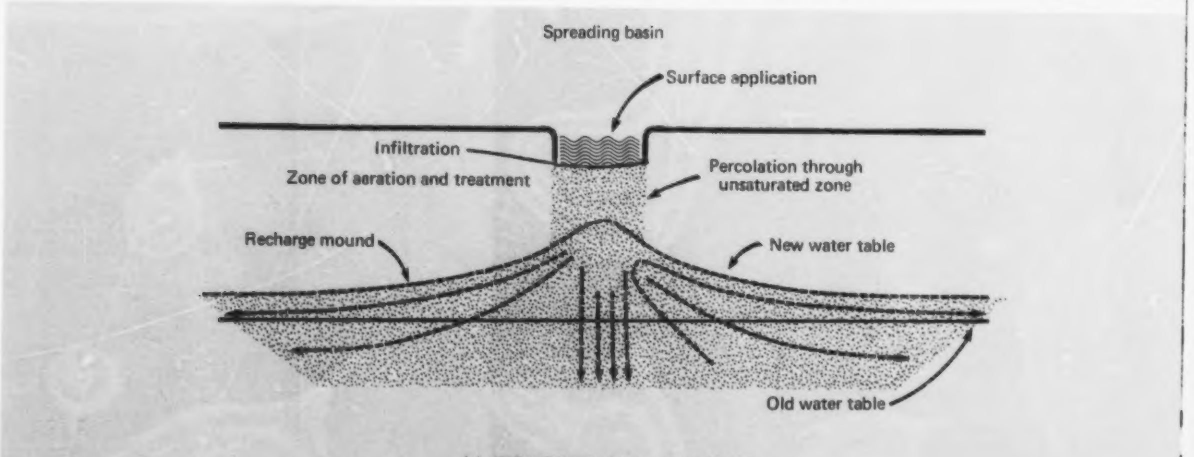
In the *irrigation mode,* the wastewater is applied to the land by sprinkling or by surface spreading. Sprinkling systems may be either fixed or moving. Fixed sprinkling systems, often called solid set systems, may be either on the


Evaporation
Spray or surface application
Crop
Root zone
Slope variable
Subsoil
Deep percolation

(a) IRRIGATION


Spray application
Evaporation
Grass and vegetative litter
Slope 2-8%
Sheet flow
Runoff collection
Percolation
100-300 ft

(b) OVERLAND FLOW


Spreading basin
Surface application
Infiltration
Zone of aeration and treatment
Percolation through unsaturated zone
Recharge mound
New water table
Old water table

(c) INFILTRATION-PERCOLATION

ground surface or buried. Both types usually consist of impact sprinklers on risers that are spaced along lateral pipelines, which are in turn connected to main pipelines. These systems are adaptable to a wide variety of terrains and may be used for irrigation of either cultivated land or woodlands. There are a number of different moving sprinkling systems, but the center pivot system is generally the most widely used for wastewater irrigation.

The two main types of surface application systems are ridge-and-furrow and flooding techniques. Ridge-and-furrow irrigation is accomplished by gravity flow of effluent through furrows from which it seeps into the ground.

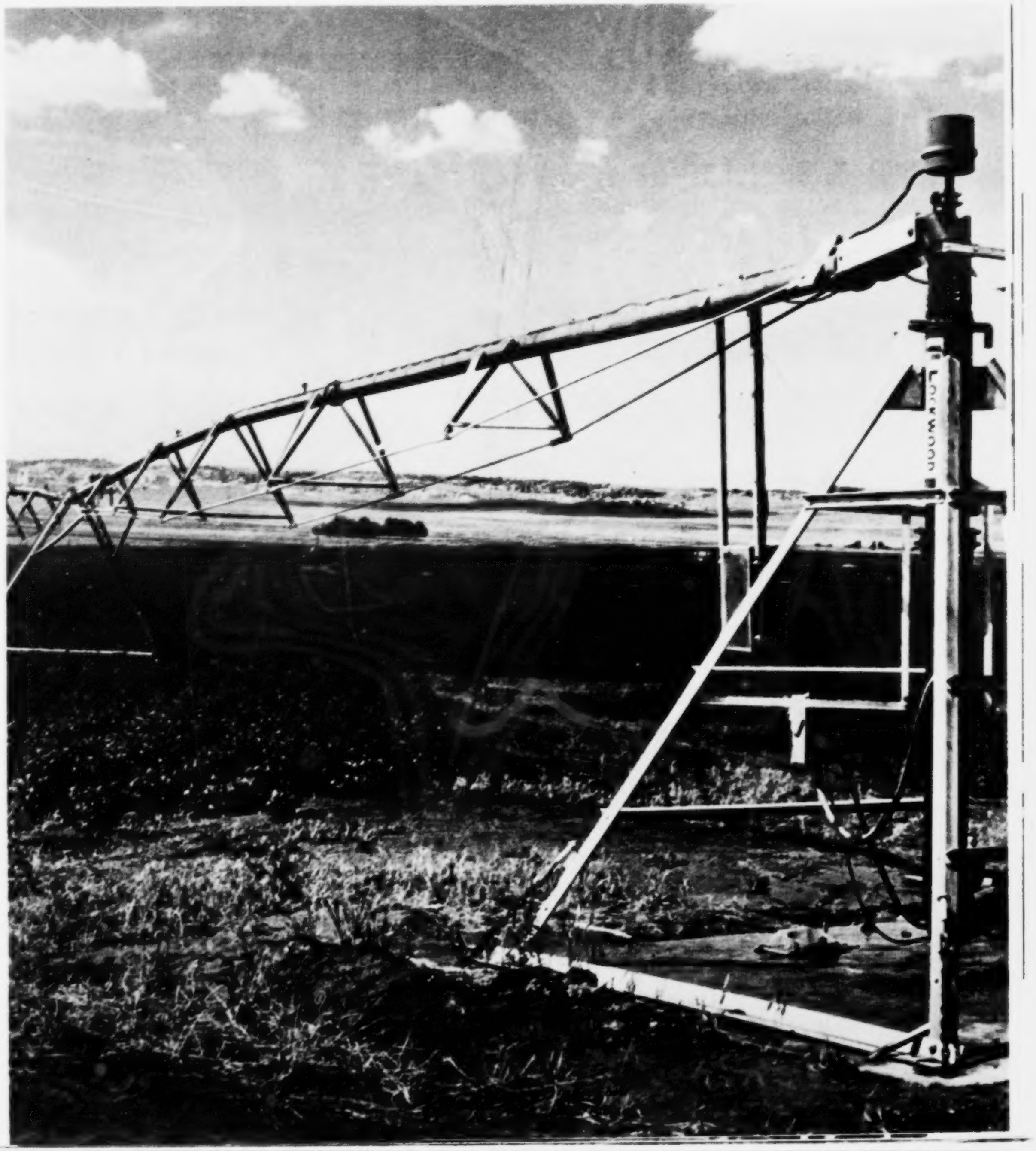
The irrigation techniques all apply the wastewater to the land so that some pollutants are taken up in the growing plants, some are transformed in the soil to harmless agents, and some are held in the soil. Some of the purified wastewater percolates through the soil to become ground water, some is taken up by plants, some runs off, and some evaporates. Typical removals of pollutants from secondary effluent by irrigation are BOD, 98 percent; COD, 80 percent; suspended solids, 98 percent; nitrogen, 85 percent; phosphorus, 95 percent; metals, 95 percent; and micro-organisms, 98 percent.

An example of an irrigation system is in Lubbock, Texas, where 15 mgd of secondary effluent is applied to 2,300 acres of a farmer's cropland. Crops consist of small grains—such as wheat, barley, oats, and rye—cotton, and many varieties of grain sorghums. Crop yields exceed those achieved with conventional irrigation.

A major spray irrigation project has been installed at Muskegon, Michigan. This 43.4-mgd project irrigates 6,300 acres of a 10,000-acre

site with secondary effluent. The wastewater from several municipalities and industries in Muskegon County is collected and treated in aerated lagoons. The lagoon effluent is then sprayed onto farmland for irrigation. Corn is the primary crop grown at Muskegon. Crop yields have been as high as 80 bushels per acre and have produced income of up to $1,000,000 per year. The system was constructed for a cost of $42.0 million in 1974. Treated wastewater collected from underdrains beneath the irrigated area is of extremely high quality, as reflected by analyses that show a BOD of 2 mg/l, total organic carbon of 5 mg/l, and phosphate of 0.05 mg/l.

In an *overland flow* system, the wastewater is sprayed over the upper edges of sloping terraces and flows slowly down the hill and through the grass and vegetative litter. Although the soil is not the primary filter in this mode, treatment efficiencies are high in a well-operated system. Typical removals are BOD, 92 percent; suspended solids, 92 percent; nitrogen, 70-90 percent; phosphorus, 40-80 percent; and metals, 50 percent. Soils best suited for this approach are clays and clay loams with even, moderate slopes (2-6 percent). Grass is usually planted to provide a habitat for biota and to prevent erosion. As the effluent flows down the slope, a portion infiltrates into the soil, a small amount evaporates, and the remainder flows to collection channels. As the effluent flows through the grass, the suspended solids are filtered out and the organic matter is oxidized by the bacteria living in the vegetative litter. Overland flow treatment has been used in the United States primarily for treating high-strength wastewater, such as that from canneries. In Australia, overland flow or grass filtration has



been used for municipal waste treatment for many years.

In *infiltration-percolation* systems, the primary goal is to recharge ground water by percolating as much wastewater as possible into the ground by placing the wastewater (after secondary treatment) into spreading basins. The distinction between treatment and disposal for this process is quite fine. Wastewater applied to the land for the purpose of disposal is also undergoing treatment by infiltration and percolation. Typical removals of pollutants from secondary effluent are BOD, 85-99 percent; suspended solids, 98 percent; nitrogen, 0-50 percent; phosphorus, 60-95 percent; and metals, 50-95 percent. Infiltration-percolation is primarily a ground water recharge system, and does not attempt to recycle the nutrients through crops. Phoenix, Arizona, is now installing an infiltration system to recharge ground water used for unrestricted irrigation.

When properly designed and operated, a land treatment system of the irrigation type can produce an effluent quality comparable to that produced by other AWT processes for phosphorus, suspended solids, BOD, heavy metal, virus, and bacterial removal. Comparable nitrogen removals can also be produced, but the nitrogen removal achieved in a land treatment system depends directly on the specific design and operating procedures used. For example, while phosphorus is readily removed by chemical reactions with the soil, the chief mechanism for nitrogen removal is uptake by crops. High degrees of nitrogen removal require that wastewater be applied to the land only during the season of active crop growth. In many parts of the country, this requirement and the need to avoid applying wastewater to frozen land frequently dictate that storage lagoons with capacity to store 3-5 months of wastewater be con-

structed to store wintertime wastewater flows. Land treatment also efficiently removes heavy metals. These metals may accumulate and persist in the soil, however, and their long-term effects must be evaluated carefully for the specific wastewater and soil conditions involved.

Examples of municipalities currently using land treatment include Muskegon County, Michigan (43.4 mgd); Tallahassee, Florida (2.5 mgd); Oceanside (1.5 mgd), Pleasanton (1.3 mgd), Golden Gate Park, San Francisco (1 mgd), Santee (1 mgd), and Bakersfield (12.3 mgd), California; St. Charles, Maryland (0.5 mgd); Colorado Springs, Colorado (5.5 mgd); and Ephrata, Washington (0.44 mgd).

Advantages. Land treatment provides a very advanced degree of treatment without generating any chemical sludges. It recycles the water and the nutrients contained in the wastewater for productive uses, and may even enable reclamation of unproductive land while reducing the use of other water resources. High degrees of treatment are achieved without consumption of resources such as chemicals and activated carbon. Large open space areas are preserved with potential for multiple recreational use during the nonirrigation season. Operating costs are less than for other tertiary processes, and there is the potential for economic return from sale of crops.

Disadvantages. The large land areas required may be a disadvantage, especially in urbanized areas. Although there are many existing systems, operation frequently has been based on what was observed to work without nuisance. The monitoring of effluent quality and the determination of system design limitations have often been inadequate. As a result, there is little U.S. experience available that is of direct assistance in designing a land treatment system that will provide high levels of treatment. Crop selection is restricted by health and other factors dictated by wastewater treatment rather than agricultural considerations.

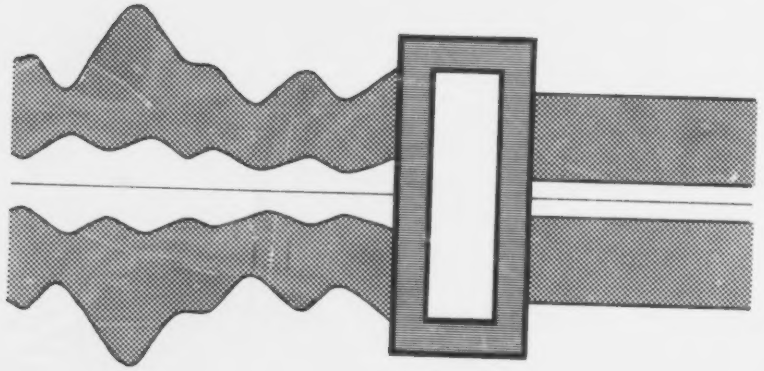
Energy Requirements. Power requirements for land treatment are extremely variable and difficult to generalize. The type of irrigation system used has a major effect; spray irrigation consumes more power than overland flow. A major variable is the amount of power required to transport wastewater from its source to a suitable land treatment site. Typical power consumption may range from about 25 kwh per million gallons for infiltration-percolation by flooding to over 1,300 kwh per million gallons for spray irrigation.

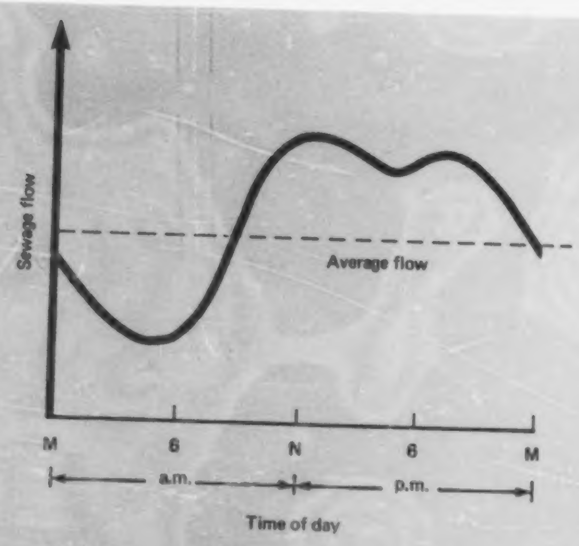
Space Requirements. The space requirements are a function of the level of treatment required and the soil type. They range from 100 to 600 acres per mgd capacity.

Costs. Costs are also highly varible, depending on space requirements for a specific project, local land costs, specific irrigation system used, etc. Total system costs include pretreatment, storage, distribution to the irrigated area, site acquisition and preparation, and drainage systems. Costs for irrigation systems can range from 40-200 cents per 1,000 gallons at 1 mgd ($4.20-$21 per month per home) to 25-170 cents per 1,000 gallons at 10 mgd ($2.60-$18 per month per home); for infiltration-percolation, from 30-60 cents per 1,000 gallons at 1 mgd ($3.15-$6.30 per month per home) to 15-45 cents per 1,000 gallons at 10 mgd ($1.60-$4.75 per month per home). Overland flow system costs usually fall between these two extremes. Land needed for storage reservoirs and for the irrigated area can be purchased or leased through federal pollution control grants.

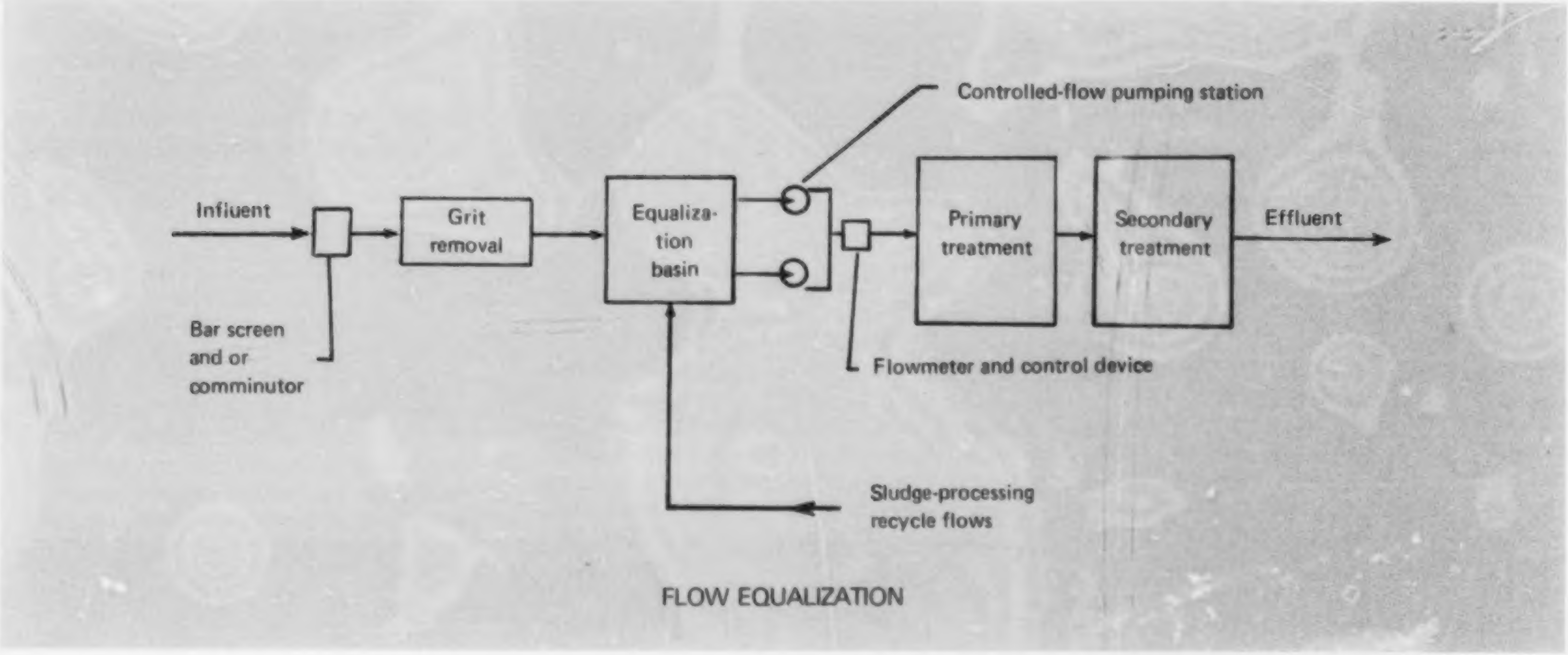
flow equalization

Flow equalization is not a treatment process per se, but a technique that can be used to improve the effectiveness of both secondary and tertiary processes. Wastewater does not flow into a municipal wastewater treatment plant at a constant rate. The flow rate varies from hour to hour, reflecting the living habits of the area served. In most towns, the pattern of daily activities begins with rising between 6 and 7 a.m., going to work between 8 and 9 a.m., lunch between 12 and 1 p.m., returning home between 4 and 5 p.m., dinner at 6 or 7 p.m., and bed by 11 p.m. This routine sets the pattern of sewage flow and strength. Above-average sewage flows and strength occur in midmorning. The constantly changing amount and strength of wastewater to be treated makes efficient process operation difficult. Also, many treatment units must be designed for the maximum flow conditions encountered, which actually results in their being oversized for average conditions. The purpose of flow equalization is to dampen these variations so that the wastewater can be treated at a nearly constant flow rate. Flow equalization, at low cost, can





VARIATIONS IN SEWAGE FLOW
DURING A TYPICAL DAY


Controlled-flow pumping station
Influent
Grit removal
Equalization basin
Primary treatment
Secondary treatment
Effluent
Bar screen and or comminutor
Flowmeter and control device
Sludge-processing recycle flows

FLOW EQUALIZATION

significantly improve the performance of an existing plant and increase its useful capacity. In new plants, flow equalization can reduce the size and cost of the treatment units.

Flow equalization is usually achieved by constructing large basins or ponds that collect and store the wastewater flow and from which the wastewater is pumped to the treatment plant at a constant rate. These units are normally located near the head end of the treatment works, preferably downstream of pretreatment facilities such as bar screens, comminutors, and grit chambers. Adequate aeration and mixing must be provided to prevent odors and solids deposition.

Flow equalization will normally improve the suspended solids removal in a primary clarifier, stabilize the operation of the biological secondary processes, and improve secondary clarifier performance. In AWT processes, flow equalization eases control of chemical addition and substantially reduces costs of filters and carbon columns by permitting them to be sized for average flows rather than peak flows.

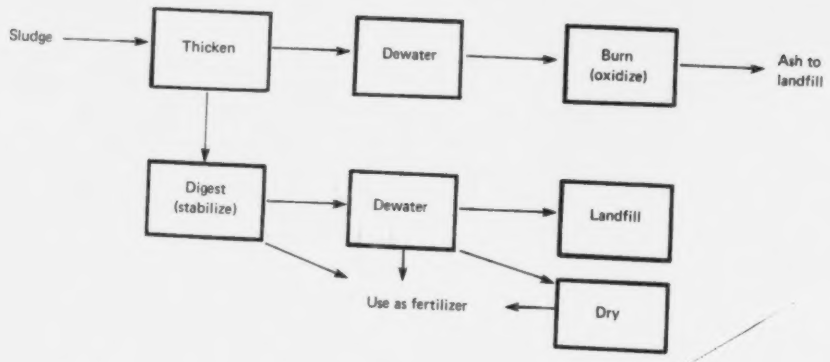
The needed basins may be constructed of earth, concrete, or steel, or may even sometimes be converted treatment units such as former sludge lagoons, aeration basins, or clarifiers. The cost of equalization will vary from one application to another, depending on the basin size, design and material selected, mixing and aeration requirements, availability of land, location of facility, and pumping requirements. Generally, the cost of equalization is only 1-5 cents per 1,000 gallons. These costs may be more than offset by savings in downstream treatment processes.

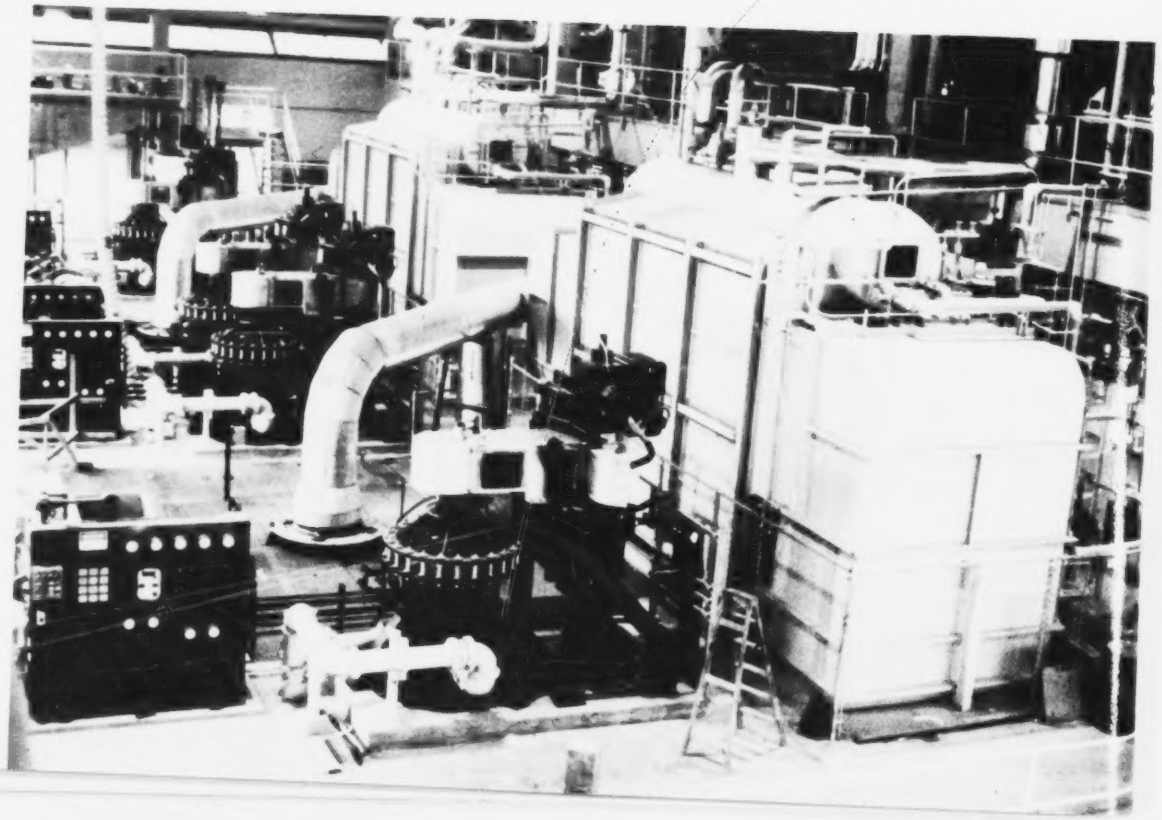
sludge treatment and disposal

In the process of purifying the wastewater, another problem is created—sludge handling. The higher the degree of wastewater treatment, the larger the residue of sludge that must be handled. Satisfactory treatment and disposal of the sludge can be the single most complex and costly operation in a municipal wastewater treatment system. The sludge is made of materials settled from the raw wastewater—such as rags, sticks, and organic solids—and of solids generated in the wastewater treatment processes—such as the excess activated sludge created by aeration or the chemical sludges produced in some AWT processes. Whatever the wastewater process, there is always something that must be burned, buried, treated for reuse, or disposed of in some way.

The quantities of sludge involved are significant. For primary treatment, they may be 2,500-3,500 gallons per million gallons of wastewater treated. When treatment is upgraded to activated sludge, the quantities increase by 15,000-20,000 gallons per million gallons. Use of chemicals for phosphorus removal can add another 10,000 gallons. For a typical activated-sludge plant, the amount of sludge to be disposed of is typically about 1 ton per million gallons or about 20 pounds per month per home. Although the amount of sludge can vary depending on the process design and the nature of the wastewater being treated, this typical quantity can be used to put monthly costs in perspective. A cost of $50 per ton is equivalent to $0.50 per month per home. The

BASIC SLUDGE-HANDLING ALTERNATIVES





sludges withdrawn from the treatment processes are still largely water, as much as 97 percent! Sludge treatment processes, then are concerned with separating the large amounts of water from the solid residues. The separated water is returned to the wastewater plant for processing.

The basic functions of sludge treatment are

- Conditioning—treatment of the sludge with chemicals or heat so that the water may be readily separated
- Thickening—separation of as much water as possible by gravity or flotation process
- Dewatering—further separation of water by subjecting the sludge to vacuum pressure, or drying processes
- Stabilization—stabilization of the organic solids so that they may be handled or used as soil conditioners without causing a nuisance or health hazard through processes referred to as "digestion"
- Reduction—reduction of the solids to a stable form by wet oxidation processes or incineration

Although a large number of alternative combinations of equipment and processes are used for treating sludges, the basic alternatives are fairly limited. The ultimate depository of the materials contained in the sludge must either be land, air, or water. Current policies discourage practices such as ocean dumping of sludge. Air pollution considerations necessitate air pollution facilities as part of the sludge incineration process. Thus, the sludge in some form will eventually be returned to the land. The following paragraphs discuss the processes employed in the basic alternative routes by which this may occur.

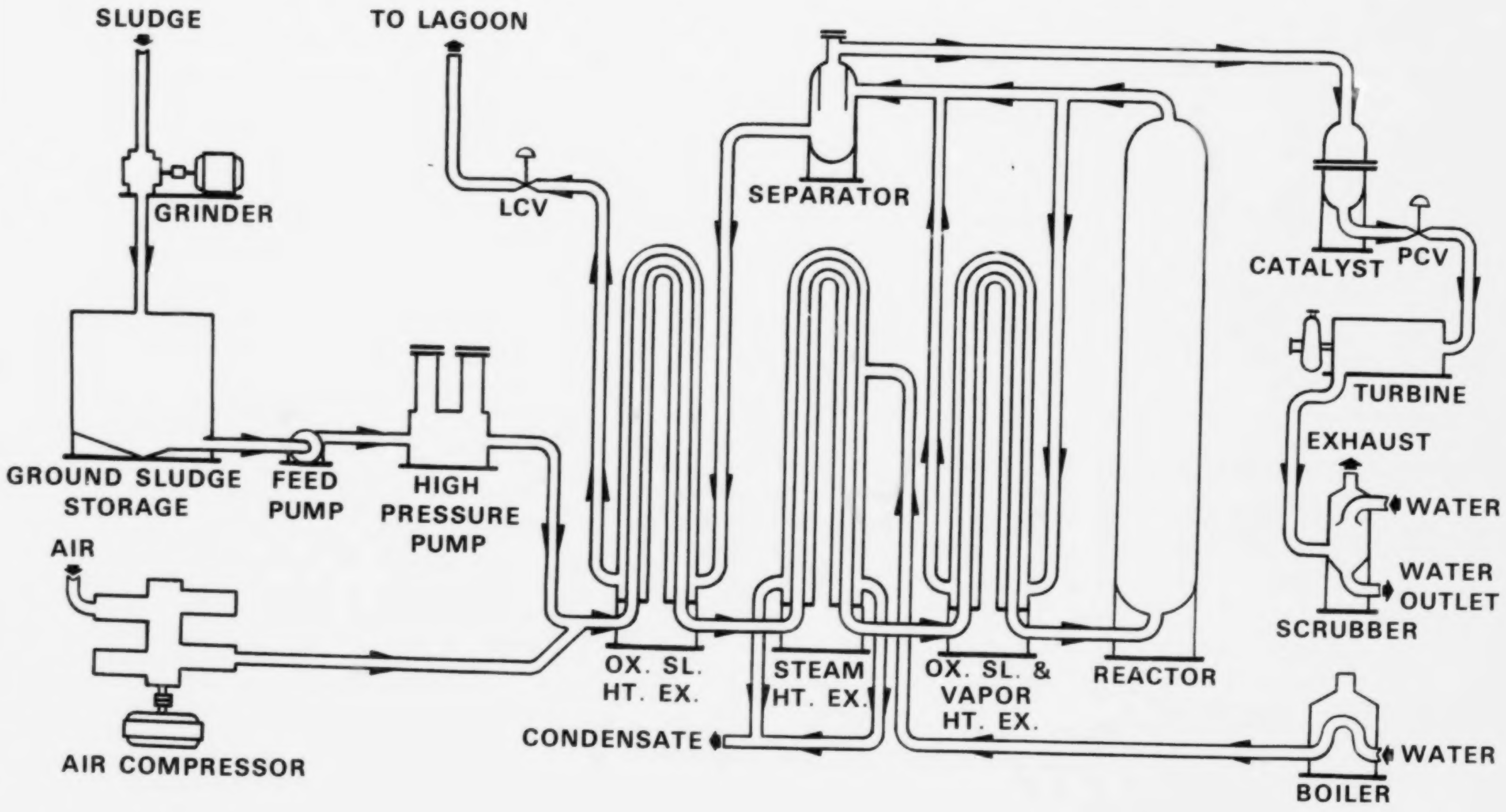
sludge conditioning

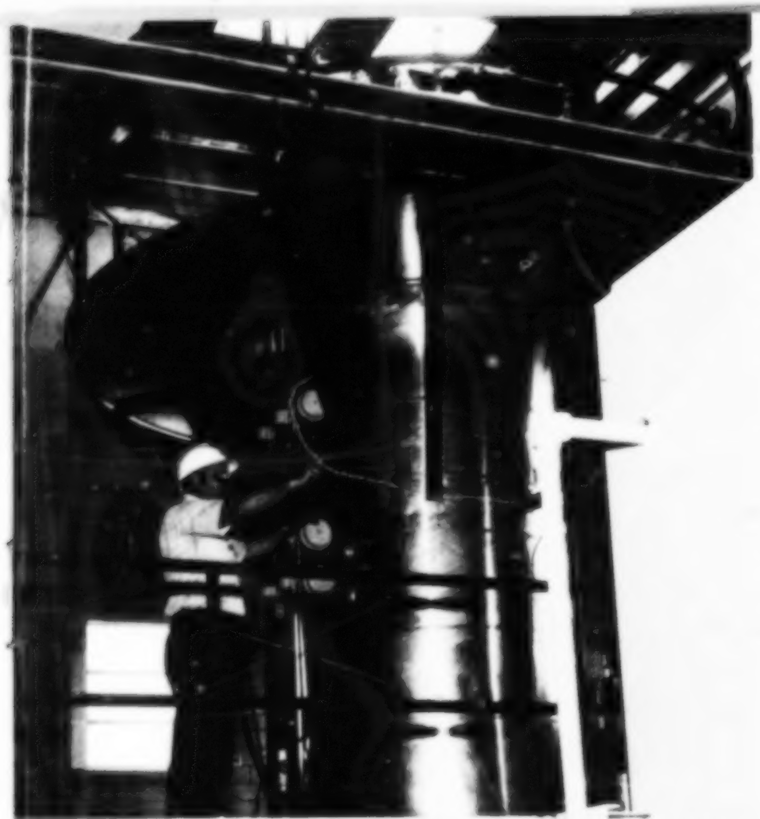
Several methods of conditioning sludge to facilitate the separation of the liquid and solids are available. One of the most commonly used is the addition of coagulants—ferric chloride, lime, or organic polymers. Ash from incinerated sludge has also found use as a conditioning agent. Just as when coagulants are added to the wastewater, chemical coagulants act to clump the solids together so that they are more easily separated from the water. In recent years, organic polymers have become increasingly popular for sludge conditioning. Polymers are easy to handle, require little storage space, and are very effective. The conditioning chemicals are injected into the sludge just ahead of thickening or dewatering processes and are mixed with the sludge. Chemical sludge conditioning is used at hundreds of municipal plants.

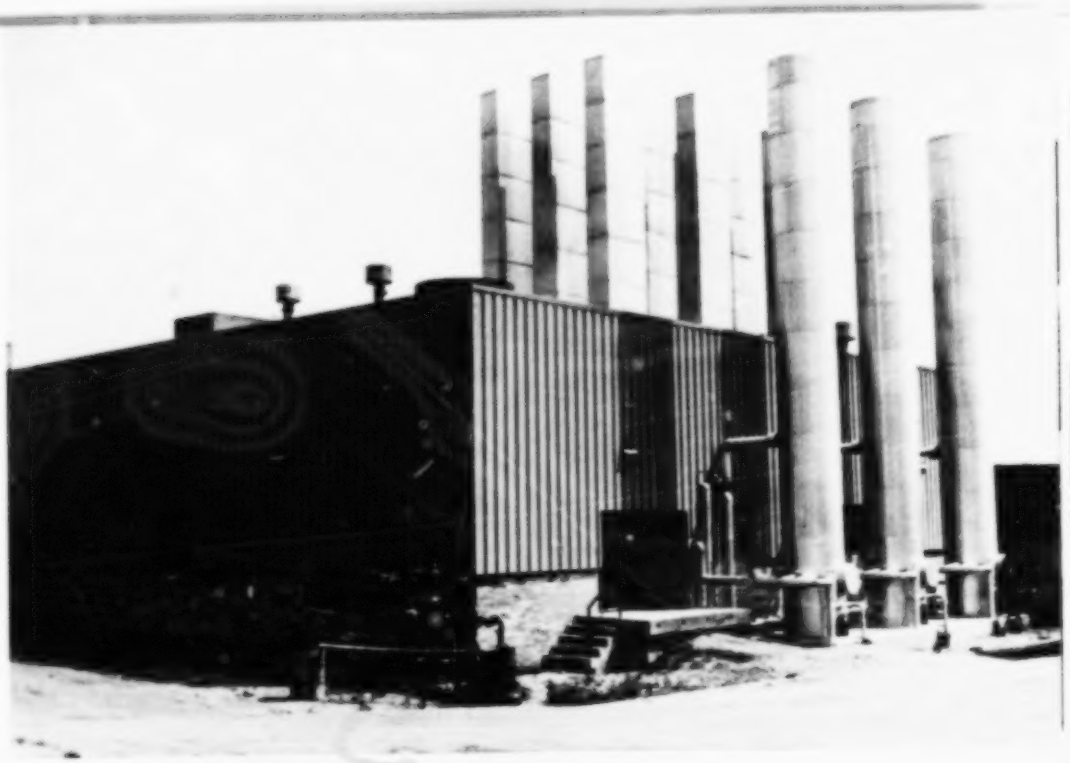
Another conditioning approach is to heat the sludge at high temperatures (350-450° F) and pressures (150-300 pounds per square inch, or psi). Under these conditions—much like those of a pressure cooker—water bound up in the solids is released, improving the dewatering characteristics of the sludge. Commercial systems first grind the sludge and then inject it into a reactor where high temperature and pressure are applied. The sludge flows from the reactor to a settling tank, where the solids are concentrated before being sent on to the dewatering step. Units of this type have been used at several plants, including Colorado Springs, Colorado; Levittown and Lancaster, Pennsylvania; Kalamazoo, Midland, and Grand Haven, Michigan; Terre Haute, Indiana; Rothschild, Wisconsin; Louisville, Kentucky; Fort Lauderdale, Florida; Columbus, Akron, and Canton, Ohio; Cambridge, Maryland; Millville, New Jersey; Denton, Texas; and Groton, Connecticut. Several other new installations are now underway. Heat treatment has the advantage of producing a sludge that dewaters better than chemically conditioned sludge. The process has the disadvantages of relatively complex operation and maintenance and the creation of highly polluted cooking liquors that, when recycled to the treatment plant, impose a significant added treatment burden.

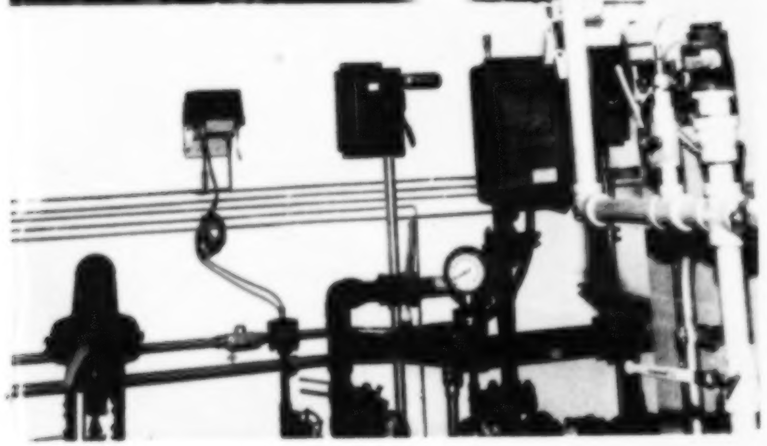
Another approach to conditioning is the application of heavy doses of chlorine to the sludge under low pressure (30-40 psi). This approach, because of the acidic effects of the chlorine, also provides stabilization of organic sludges.

Chemical conditioning costs may range from $10-$25 per ton—the higher the proportion of activated sludge, the more difficult and expensive the conditioning process. Power requirements for chemical addition range from 3-10 kwh per ton. Heat treatment costs typically are $60-$90 per ton of solids for a wastewater treatment plant in the size range of 5-10 mgd. The process is not often used in smaller plants because costs become too high. Electricity requirements for heat treatment range from about 70-140 kwh per ton, while fuel consumption ranges from 4-7 million Btu per ton.


SLUDGE
TO LAGOON
GRINDER
LCV
SEPARATOR
CATALYST
PCV
TURBINE
GROUND SLUDGE STORAGE
FEED PUMP
HIGH PRESSURE PUMP
EXHAUST
WATER
AIR
WATER OUTLET
SCRUBBER
OX. SL. HT. EX.
STEAM HT. EX.
OX. SL. & VAPOR HT. EX.
REACTOR
CONDENSATE
WATER
BOILER
AIR COMPRESSOR





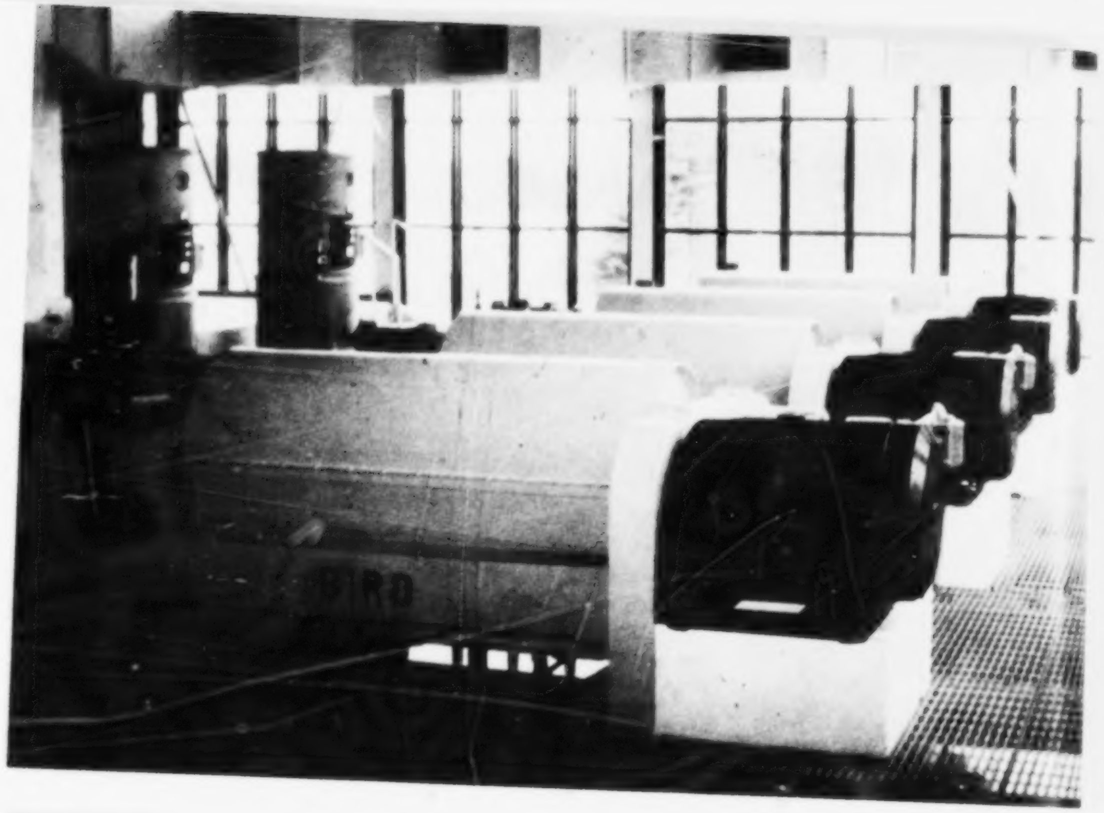


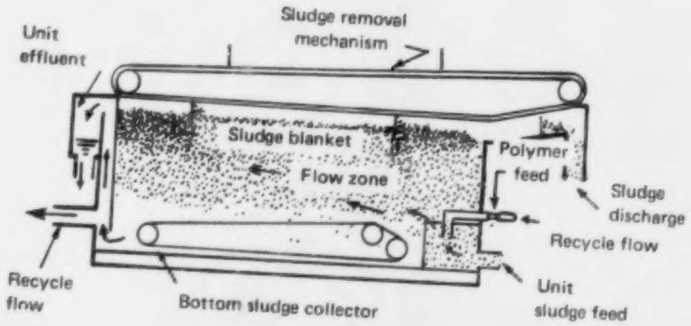
sludge thickening

After the sludge has been conditioned, it is often thickened before further processing. Thickening is usually accomplished in one of two ways: the solids are floated to the top of the liquid (flotation thickening) or are allowed to settle to the bottom (gravity thickening). The goal is to remove as much water as possible before final dewatering or disposal of the sludge. The processes involved offer a low-cost means of reducing sludge volumes by a factor of 2 or more. The costs of thickening are usually more than offset by the resulting savings in the size and cost of downstream sludge-processing equipment.

The flotation thickening process injects air into the sludge under pressure (40-80 psi). Under this pressure, a large amount of air can be dissolved. The sludge then flows into an open tank where, at atmospheric pressure, much of the air comes out of solution as minute air bubbles that attach themselves to sludge solids particles and float them to the surface. Flotation is especially effective on activated sludge, which is difficult to thicken by gravity. The sludge forms a layer at the top of the tank; this layer is removed by a skimming mechanism for further processing. The process typically increases the solids content of activated sludge from 0.5-1 to 3-6 percent, greatly easing further dewatering.

Gravity thickening has been used widely on primary sludges for many years. It is simple and inexpensive. It is essentially a sedimentation process similar to that which occurs in all settling tanks. Sludge flows into a tank that is very similar in appearance to the circular clarifiers used in primary and secondary sedimentation;

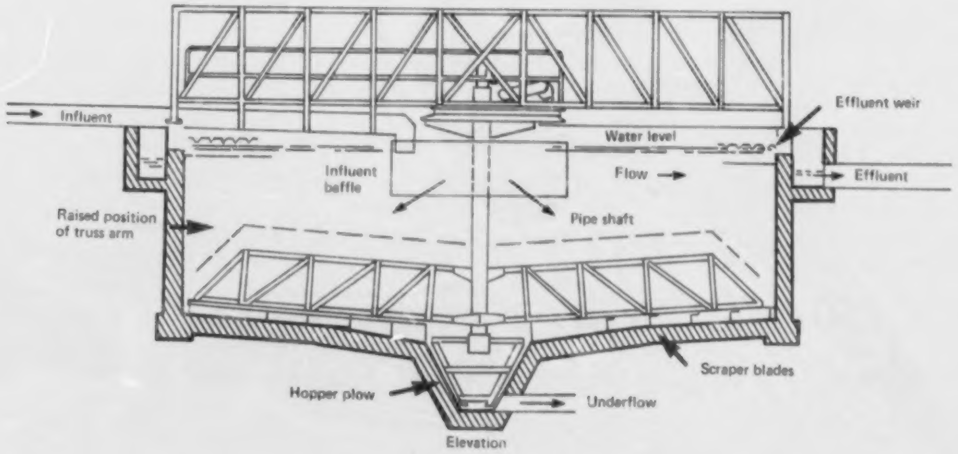




FLOTATION THICKENER

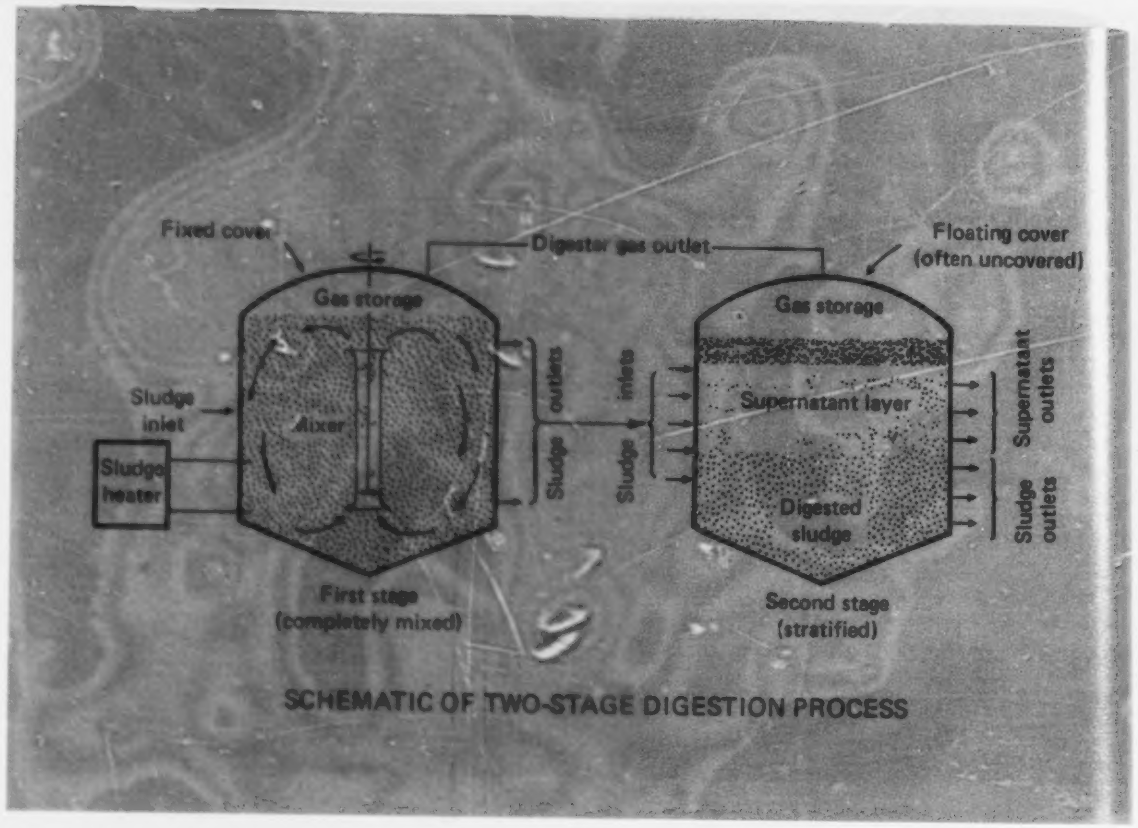
the solids are allowed to settle to the bottom where a heavy-duty mechanism scrapes them to a hopper from which they are withdrawn for further processing. The type of sludge being thickened has a major effect on performance. The best results are obtained with purely primary sludges. As the proportion of activated sludge increases, the thickness of the settled sludge solids decreases. Purely primary sludges can be thickened from 1-3 to 10 percent solids.

Costs of thickening are about $4-$10 per ton (for the 1-10 mgd plant range) for gravity thickening and $15-$20 per ton for flotation thickening. Power consumption for gravity thickening is less than 5 kwh per ton, while power consumption for flotation thickening ranges from 150-400 kwh per ton. The current trend is toward using gravity thickening for primary sludges and flotation thickening for activated sludges, and then blending the thickened sludges for further processing.


Influent
Effluent weir
Water level
Influent baffle
Flow
Effluent
Raised position of truss arm
Pipe shaft
Scraper blades
Hopper plow
Underflow
Elevation

GRAVITY THICKENER

sludge stabilization



SCHEMATIC OF TWO-STAGE DIGESTION PROCESS

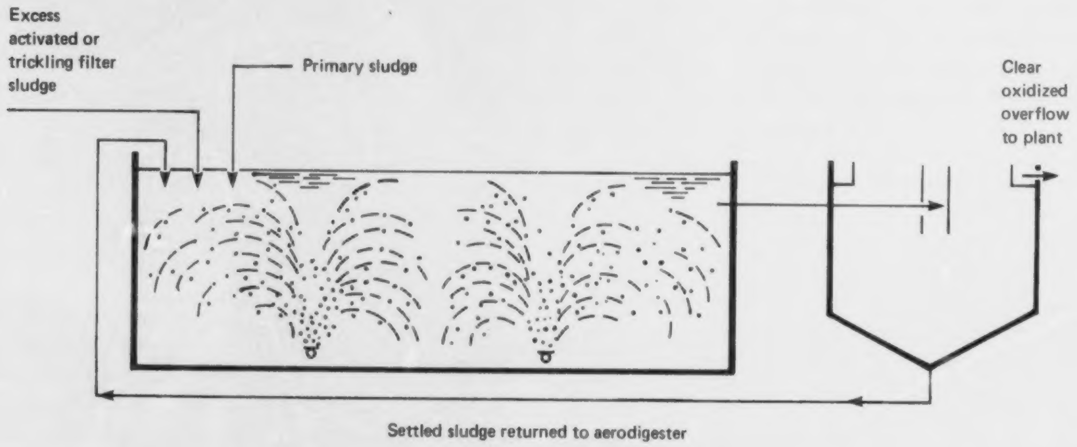
The principal purposes of sludge stabilization are to break down the organic solids biochemically so that they are more stable (less odorous and less putrescible) and more dewaterable, and to reduce the mass of sludge. If the sludge is to be dewatered and burned, stabilization is not normally used. Many municipal plants do not use incineration, however, and rely on sludge digestion to stabilize their organic sludges. There are two basic digestion processes in use. One is carried out in closed tanks devoid of oxygen and is called "anaerobic digestion." The other approach injects air into the sludge to accomplish "aerobic digestion."

Most modern anaerobic digesters use a two-stage process. The sludge is normally heated by means of coils located within the tanks or an external heat exchanger.

In the two-stage process, the first tank is used for the biological digestion. It is heated and equipped with mixing facilities. The second tank is used for storage and concentration of digested sludge and formation of a relatively clear liquid (called "supernatant") that can be withdrawn from the top of the tank and recycled to the treatment plant. The second tank may be an open tank, an unheated tank, or a sludge lagoon. Tanks are usually circular, are seldom less than 20 feet or more than 115 feet in diameter, and may be as deep as 45 feet or more. As the organic solids are broken down by anaerobic bacteria, methane gas and carbon dioxide gas are formed. Methane gas is combustible and must not be allowed to mix with air or an explosive mixture may result. The digester gas containing methane is a usable fuel, a fact that has been receiving increased attention. Digester gas may be used for digester and building heating or as fuel for internal combustion engines that are used for pumping sewage, operating blowers, and generating electricity. An efficiently operating anaerobic digester converts about 50 percent of the organic solids to liquid and gaseous forms. The methane liberated has the potential to generate about 2,100 kwh of electricity per year for every 100 people served. As compared to aerobic digestion, anaerobic digestion has the advantage of producing a useful by-product (methane) rather than consuming power. It has the disadvantage that it is sensitive to variations in sludge feed and can become easily upset if not carefully operated. It also produces a supernatant (which must be recycled to the treatment plant) containing a high concentration of soluble pollutants that are an added load on the secondary process. Costs for anaerobic digestion can range from $60-$100 per ton of dry solids, depending on the plant capacity. Power consumption for anaerobic digestion is about 90 kwh per ton, while fuel requirements are about 14 million Btu per ton. Neither figure accounts for the recovery of energy from digester gas.

Aerobic digestion is accomplished by aerating the organic sludges in an open tank resembling an activated-sludge aeration tank. (In fact, activated-sludge aeration tanks have been converted to aerobic digesters.) Its most extensive use has been in relatively small activated-sludge plants. It is receiving increased attention for larger plants, however. The process can achieve about the same 50 percent solids reduction achieved in the anaerobic process, while offering advantages of being more stable in operation and recycling fewer pollutants to the wastewater plant than anaerobic digesters. It has the disadvantages of higher power costs and does not produce an energy source such as methane. Total costs are typically $45-$100 per ton. Power requirements range from about 500-900 kwh per ton, depending on the type of aeration.

Composting of primary and secondary wastewater sludges is a means of stabilizing sludge for reuse purposes. Sludge can be composted by mixing it with a bulking agent (such as wood chips or even refuse) and placing it in piles or windrows about 7 feet high. Biological activity stabilizes the sludge and raises the temperature so high that most disease causing organisms are killed. After composting is complete (usually about 3 weeks), the material is cured for another month and then can be used as sludge conditioner. Composting has been used at Los Angeles, California; Beltsville, Maryland; Bangor, Maine; and Durham, New Hampshire. Costs for composting have been estimated at $20-$50 per ton.


Excess activated or trickling filter sludge
Primary sludge
Clear oxidized overflow to plant
Settled sludge returned to aerodigester

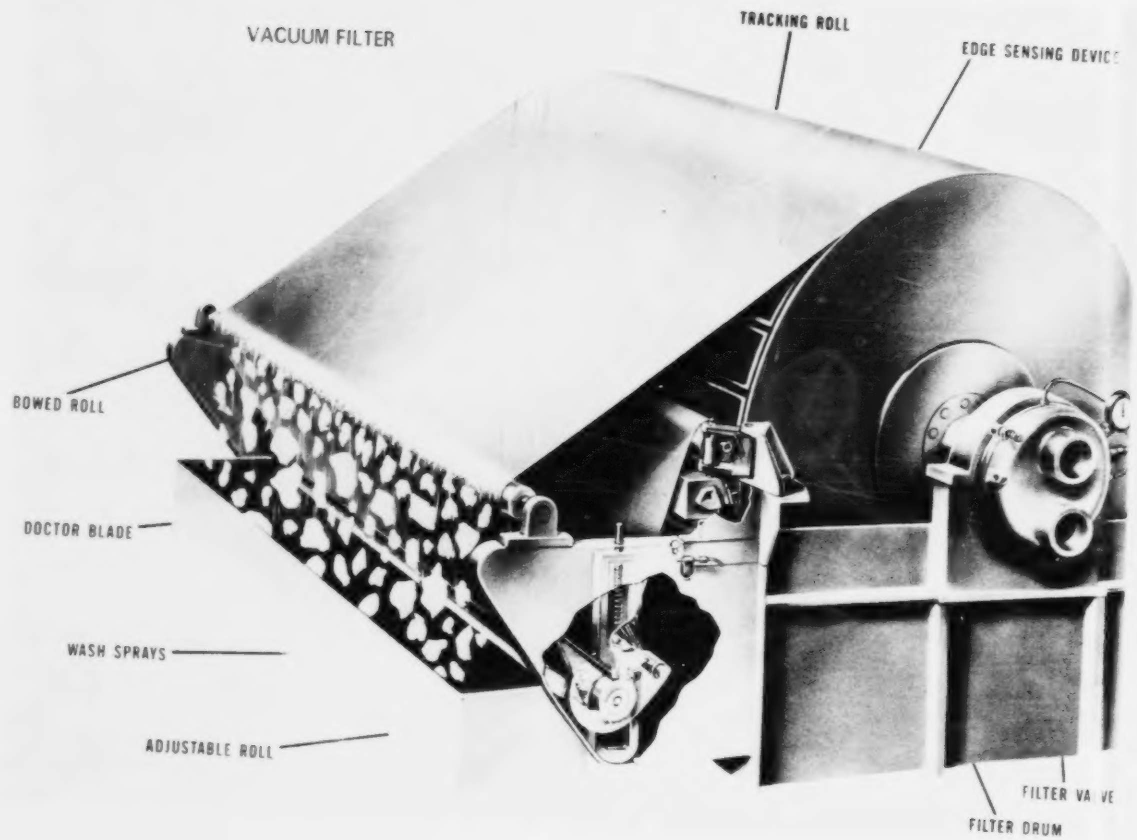
AEROBIC DIGESTION SCHEMATIC

sludge dewatering

The most widely used method for sludge dewatering in the past has been drying the sludge on sandbeds. These beds are especially popular in small plants because of their simplicity of operation and maintenance. They are usually constructed of a layer of 4-9 inches of sand placed over 8-18 inches of gravel. Sludge is drawn from the digester, placed on the sandbed, and allowed to stand until dried by a combination of drainage and evaporation. Drainage is collected in pipes beneath the gravel and returned to the wastewater plant for treatment. In good weather, the solids content can be increased to 45 percent (resembling moist dirt) within 6 weeks and can reach as high as 85-90 percent. Sandbeds have sometimes been enclosed by glass, greenhouse-type structures to protect the sludge from rain and reduce the drying period. In small plants, the dried sludge is usually removed from the drying beds by hand, while larger plants often use mechanical equipment. Although sandbeds are simple to operate, the space requirements can be a disadvantage when secondary sludge is involved. Unless the beds are covered, the performance can be markedly affected by weather. For small treatment plants, the cost of sand drying beds is typically about $30 per ton of dry solids. With increased use of secondary treatment, the use of more compact and more controllable mechanical-dewatering systems is increasing. Such systems include vacuum filters, centrifuges, and pressure filters.

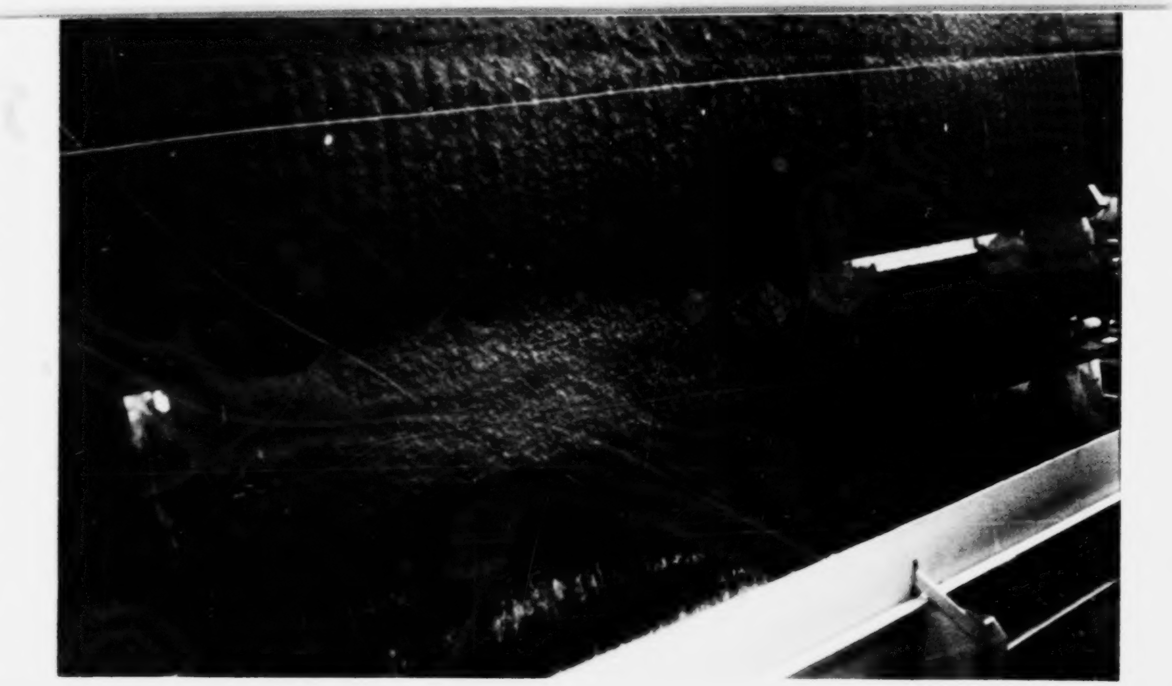
A vacuum filter basically consists of a cylindrical drum covered with a filtering material or fabric, which rotates partially submerged in a

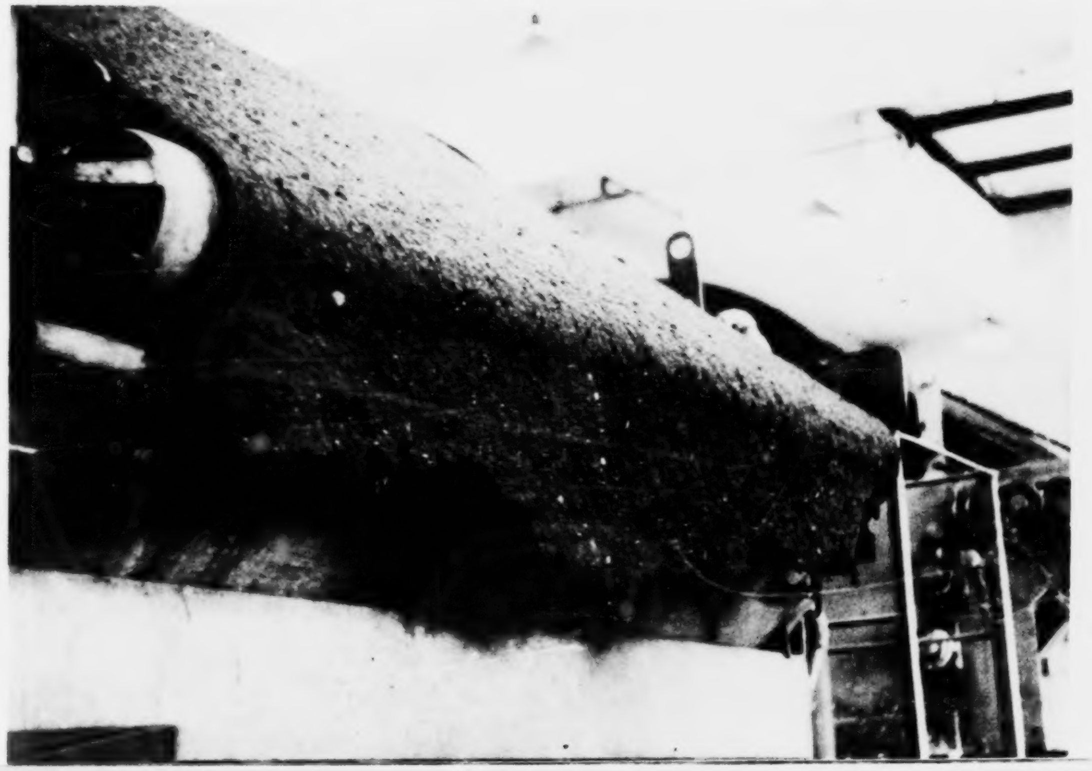
VACUUM FILTER

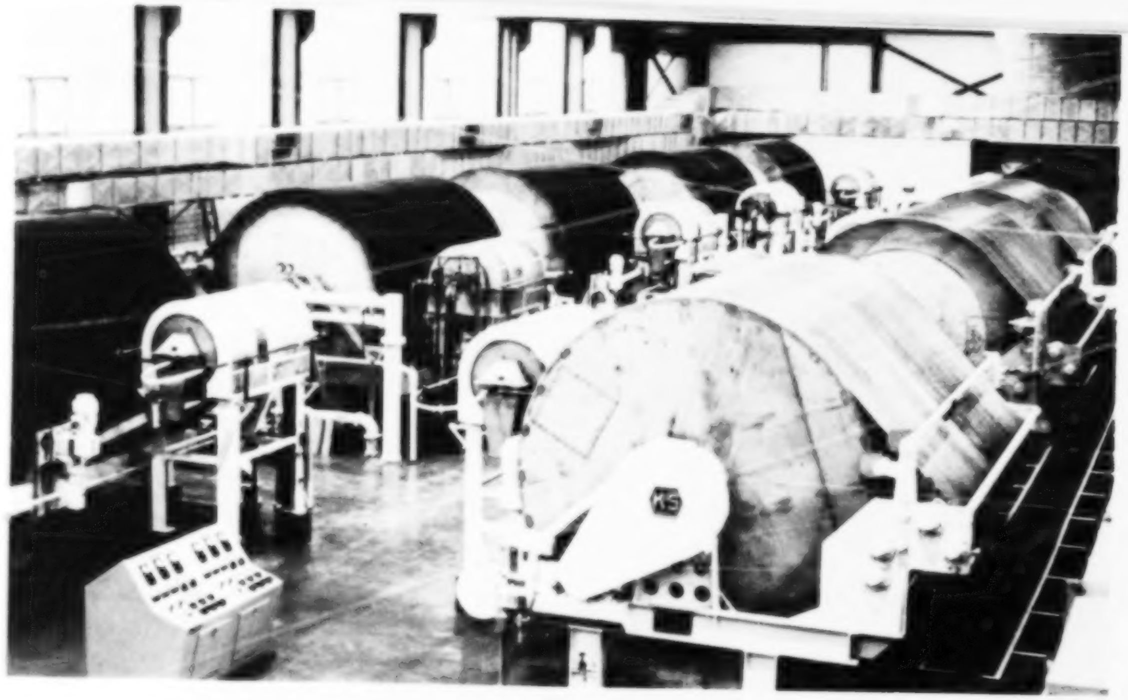


vat of conditioned sludge. A vacuum is applied inside the drum to extract water, leaving the solids or "filter cake" on the filter medium. As the drum completes its rotational cycle, a blade scrapes the filter cake from the filter and the cycle begins again. In some systems, the filter fabric passes off the drum over small rollers to dislodge the cake. There is a wide variety of filter fabrics, ranging from Dacron to stainless-steel coils, each with its own advantages. The vacuum filter can be applied to digested sludge to produce a sludge cake dry enough (15-30 percent solids) to handle and dispose of by burial in a landfill or by application to the land as a relatively dry fertilizer. If the sludge is to be incinerated, it is not necessary to stabilize the sludge by digestion. In this case, the vacuum filter is applied to the raw sludge to dewater it. The sludge cake is then fed to the furnace to be incinerated. The cost of vacuum filtration for a chemically conditioned sludge generally ranges from $40-$50 per ton of dry solids at 5-10 mgd treatment plants (not including conditioning costs); the greater the proportion of activated sludge, the greater the costs of dewatering and the wetter the sludge cake. Power consumption for vacuum filtration ranges from about 70-125 kwh per ton. Vacuum filtration has been the most popular mechanical sludge-dewatering method in the municipal field, with over 1,500 installations. While this method has the disadvantage of requiring more skilled operation than a drying bed, it has the advantages of occupying much less space and being more controllable in performance than a drying bed.

Centrifuges are also a popular means of dewatering municipal sludges. A centrifuge uses centrifugal force to speed up the separation of sludge particles from the liquid. In a typical unit, sludge is pumped into a horizontal, cylindrical, "bowl," rotating at 1,600-2,000 rpm. Polymers used for sludge conditioning also are injected



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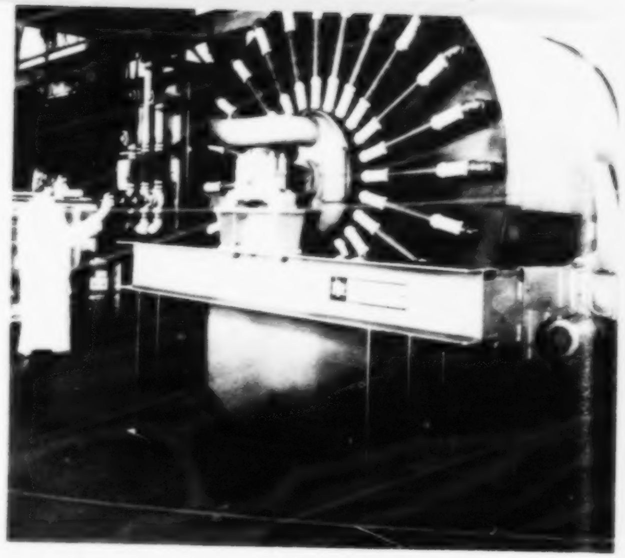
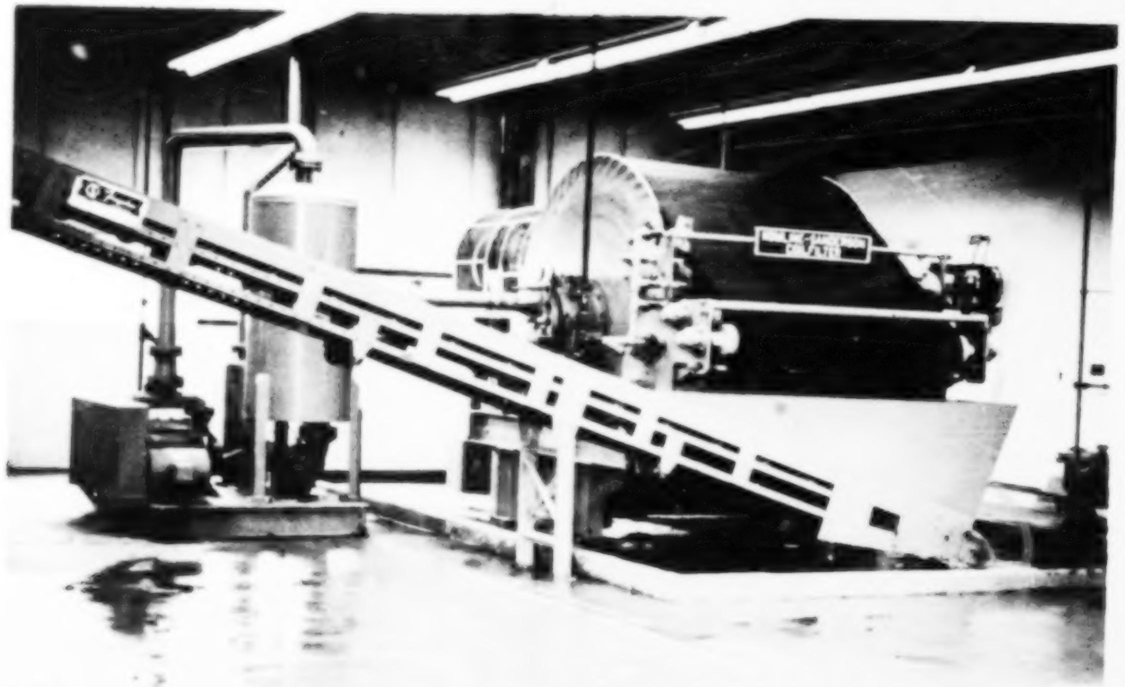
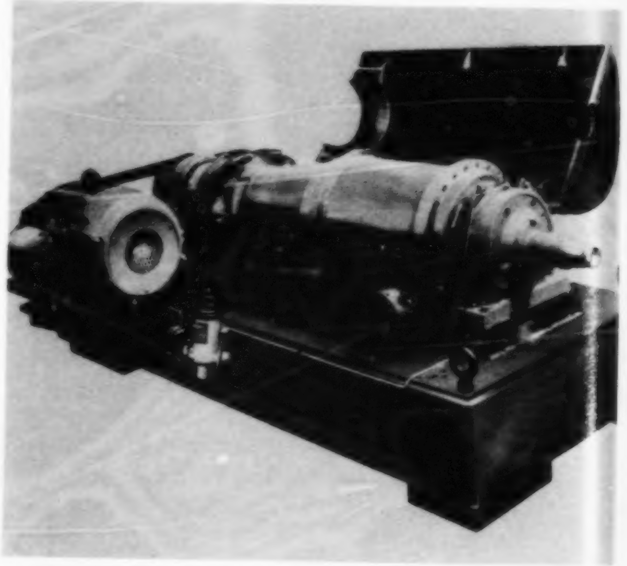
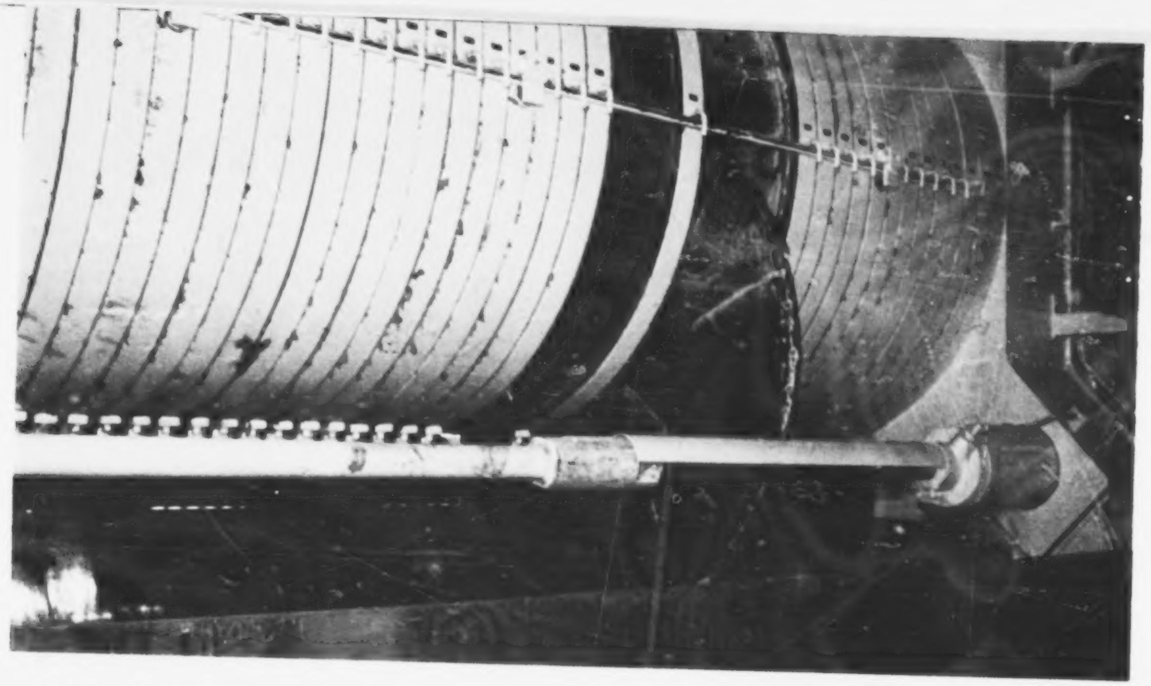


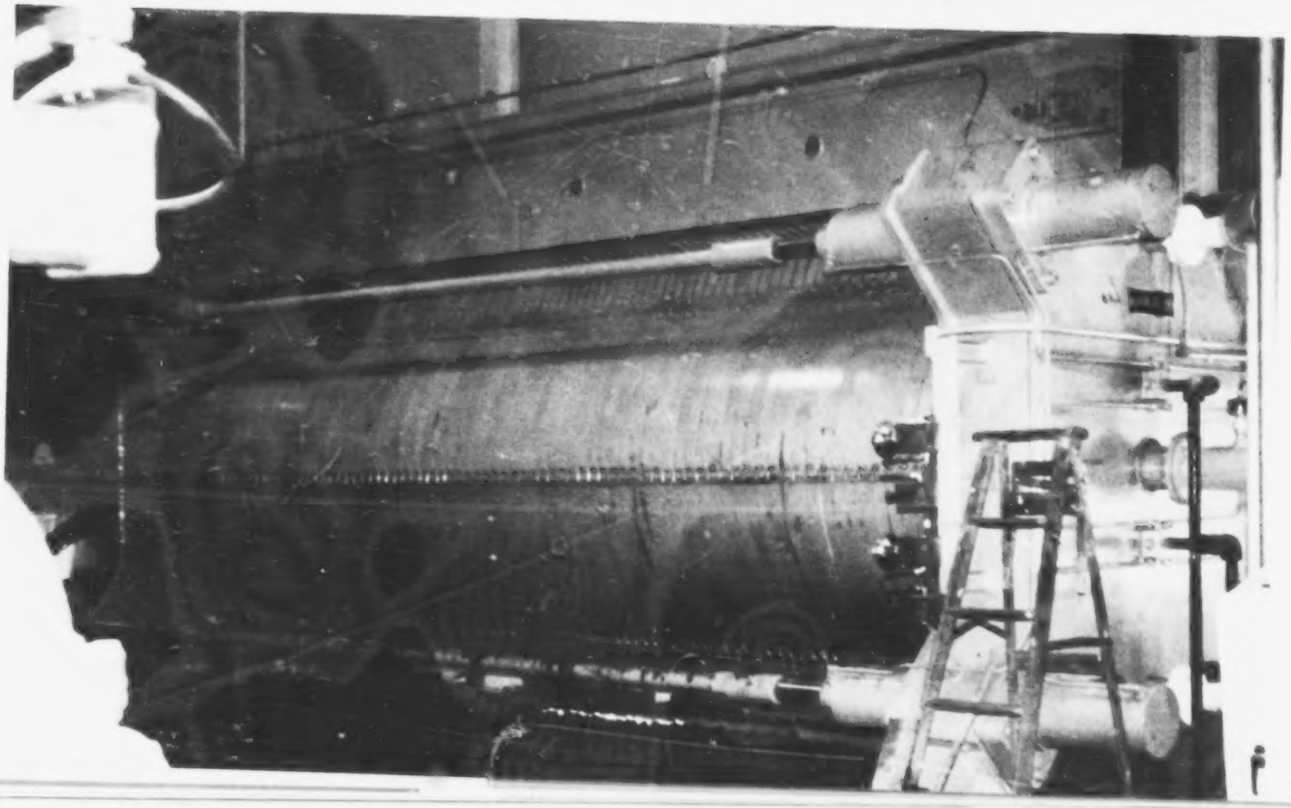




into the centrifuge. The solids are spun to the outside of the bowl where they are scraped out by a screw conveyor. The liquid, or "centrate," is returned to the wastewater treatment plant for treatment. The centrifuging process is usually comparable to vacuum filtration in costs and performance. For a 5-mgd plant costs (not including conditioning) are typically \$50-\$60 per ton of dry solids, while costs for a 10-mgd plant are \$30-\$40 per ton. Power consumption is typically 35-70 kwh per ton. Centrifugation has the advantages of being entirely enclosed, which may reduce odors, requiring a small amount of space, being able to handle some sludges that might otherwise plug vacuum filter media, and exerting large separational forces on the sludge. It has the disadvantage of being complex to maintain because of the high speed of the equipment. If grit and sand are not carefully removed, abrasion problems will occur in the centrifuge.

Pressure filtration is also an effective means of sludge dewatering that is finding increased use in the United States. Sludge is dewatered by pumping it at high pressure (up to 225 psi) through a filter medium that is attached to a series of plates. These plates are held together in a frame between one fixed end and one moving end. Sludge is pumped into the chambers between plates, so that the water passes through the filter medium and the solids are retained. Eventually, the pressure filter fills with sludge solids. Pumping of sludge is then discontinued, and the moving end of the press is pulled back so that the individual plates can be moved to dislodge the filter cake. After the cake is removed, the plates are pushed back together by the moving end and the cycle begins again. Pressure filtration offers the advantages of providing the dryest cake achievable by mechanical dewatering methods, producing a very clear filtrate for return to the treatment plant, and frequently reducing chemical conditioning costs. It has the disadvantages of being a batch-type operation, requiring operator attention at the end of each cycle and of requiring periodic washing of the filter medium. Power requirements for pressure filtration are about 40 kwh per ton of dry solids. The costs for pressure filtration are often comparable to vacuum filtration and centrifugation, but the dryer cake produce (usually 40-50 percent solids) can provide savings in total sludge-handling costs. Although popular in Europe for years, pressure filtration only recently has found extensive use in the municipal field in the United States. Interest has been spurred by recent improvements in equipment. Major systems are in operation at Cedar Rapids, Iowa, and Kenosha, Wisconsin, with many more in the design or construction stage.





use of sludge as a soil conditioner

Municipal sludge contains essential plant nutrients and useful trace elements, and has potential as a fertilizer or soil conditioner. Before such use, the sludge is nearly always stabilized by digestion or some other process to control pathogenic bacteria and viruses and to minimize the potential for odors. There are then several alternative forms of the sludge that can be used as fertilizer or soil conditioner: liquid sludge directly from the stabilization process, dewatered sludge, or dewatered and dried sludge.

Several cities apply liquid sludge to croplands. This practice has the advantage of eliminating dewatering costs, but the disadvantage of increasing the volume of sludge that must be handled and applied to the land. Such sludge is not used for root crops or crops consumed raw because of health considerations. It is frequently used for pastureland or corn, wheat, or forage crops. Smaller towns often haul the sludge in trucks that also spread the sludge on the land. Large cities usually find pumping the sludge through pipelines to the disposal site to be the cheapest method of sludge transportation. The largest operation using liquid sludge in the United States is that of the Metropolitan Sanitary District of Chicago. Digested sludge is barged to strip-mined land 200 miles from Chicago and applied by spraying to restore the land to productive use. Eventually, 10,000 acres will be fertilized with the sludge. Crops grown include corn, soybeans, and winter wheat.

To reduce the volume of material handled, dewatering is sometimes used before applying the sludge to the land. In small plants, sludge removed from drying beds is often stockpiled for use by the city or by local citizens. Larger cities may use mechanical dewatering systems, with the sludge cake hauled to the disposal site where it is plowed into the ground. Large drying lagoons at the disposal site are planned by the Metropolitan Denver Sewage Disposal District to accomplish dewatering.

Heat-drying of dewatered sludge reduces the volume even further. Several major United States cities, including Houston and Milwaukee, dry their sludge for use as a soil conditioner. Houston's dried sludge is sold to a contractor in Florida, who has been using the product in citrus groves for over 10 years. The sludge is transported by rail or barge. The Milwaukee Sewerage Commission markets its heat-dried activated sludge under the trade name "Milorganite," and this is a widely used soil conditioner. It is sold, in 50-pound bags, to large distributors, who in turn market the material through jobbers in all 50 States and some foreign countries. An average analysis of Milorganite showed 6 percent nitrogen, 4 percent phosphate, 0.4 percent potash, 5 percent moisture, and numerous beneficial trace elements. Although they have recovered some of their sludge-processing costs, neither Milwaukee nor Houston has made a profit from sludge processing and sales. A changing supply in inorganic fertilizers may make this approach attractive to other cities.

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MILORGANITE
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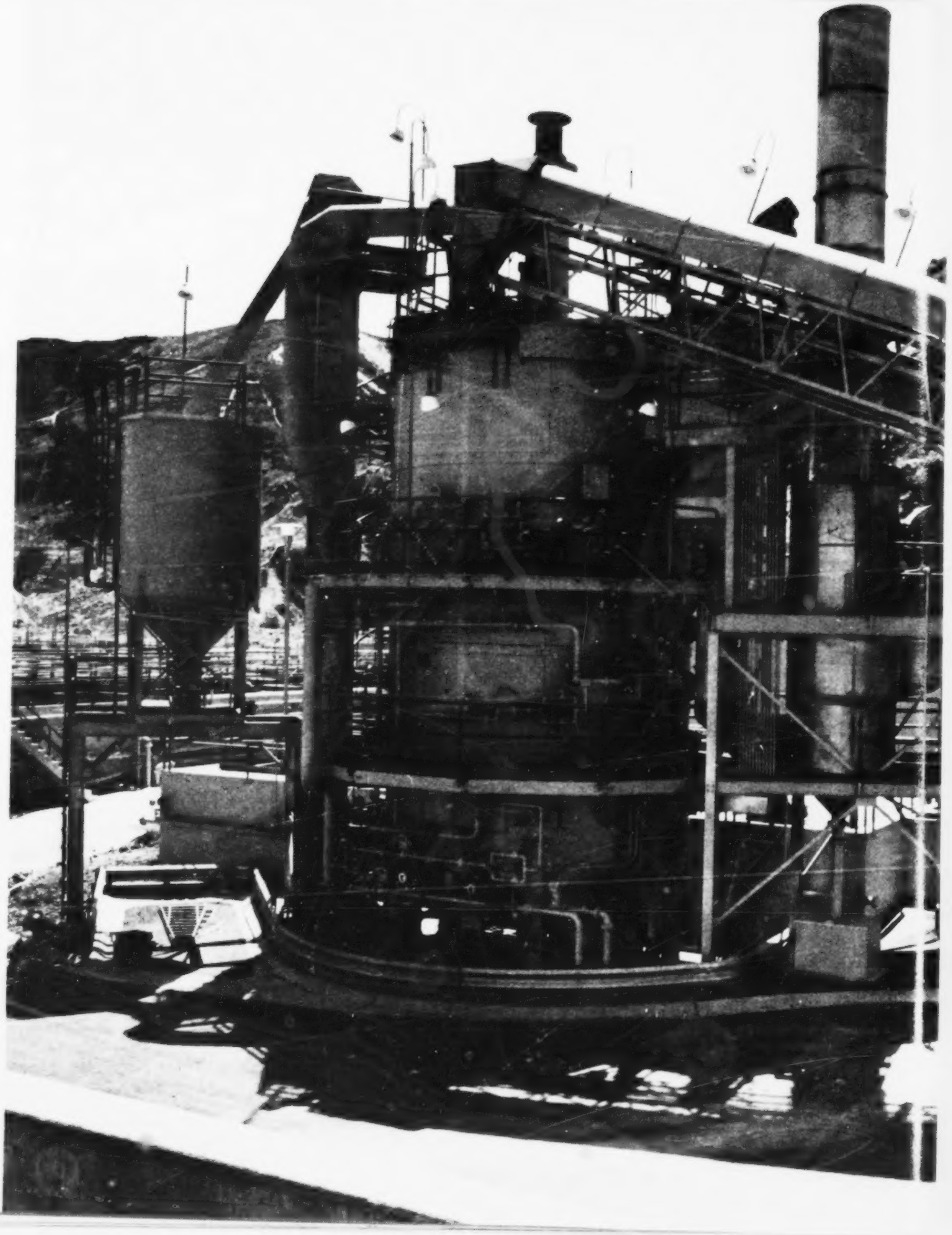
SOC

sludge reduction

If sludge use as a soil conditioner is not practical, or if a site is not available for landfill using dewatered sludge, cities may turn to the alternative of sludge reduction. Incineration completely evaporates the moisture in the sludge and combusts the organic solids to a sterile ash. To minimize the amount of fuel used, the sludge must be dewatered as completely as possible before incineration. If the sludge is dry enough, no fuel may be needed except to start up the furnace. The exhaust gases from an incinerator must be treated carefully to avoid air pollution. EPA has developed standards that insure that air quality will not be impaired by municipal sludge incinerators. The two most widely used sludge incineration systems in the United States are the multiple-hearth furnace and the fluidized-bed incinerator.

The multiple-hearth furnace is the most widely used wastewater sludge incinerator in the United States today. It is simple and durable, and has the flexibility of burning a wide variety of materials. There are over 120 of these units installed for wastewater-sludge combustion. A typical multiple-hearth furnace consists of a circular steel shell surrounding a number of hearths. Dewatered sludge enters at the top and proceeds downward through the furnace from hearth to hearth, moved by the rotary action of rabble arms driven by a central shaft. Gas or oil burners furnish heat for startup of the furnace and supplemental heat, if needed, to keep the temperature in the lower part of the furnace at 1,500° F or higher. The flue gases are



passed through a scrubbing device to control air pollution.

The first fluidized-bed municipal sludge incinerator was installed in 1962, and there are now several units operating in the United States. The fluidized-bed incinerator is a vertical steel cylinder filled with a bed of hot sand. Combustion air flows up through the bed of sand at a rate high enough to fluidize the sand. Dewatered sludge is injected into the fluidized sand where it is burned at 1,400-1,500° F. The sludge ash is carried out the top with the exhaust gases, and is removed in the air pollution control process.

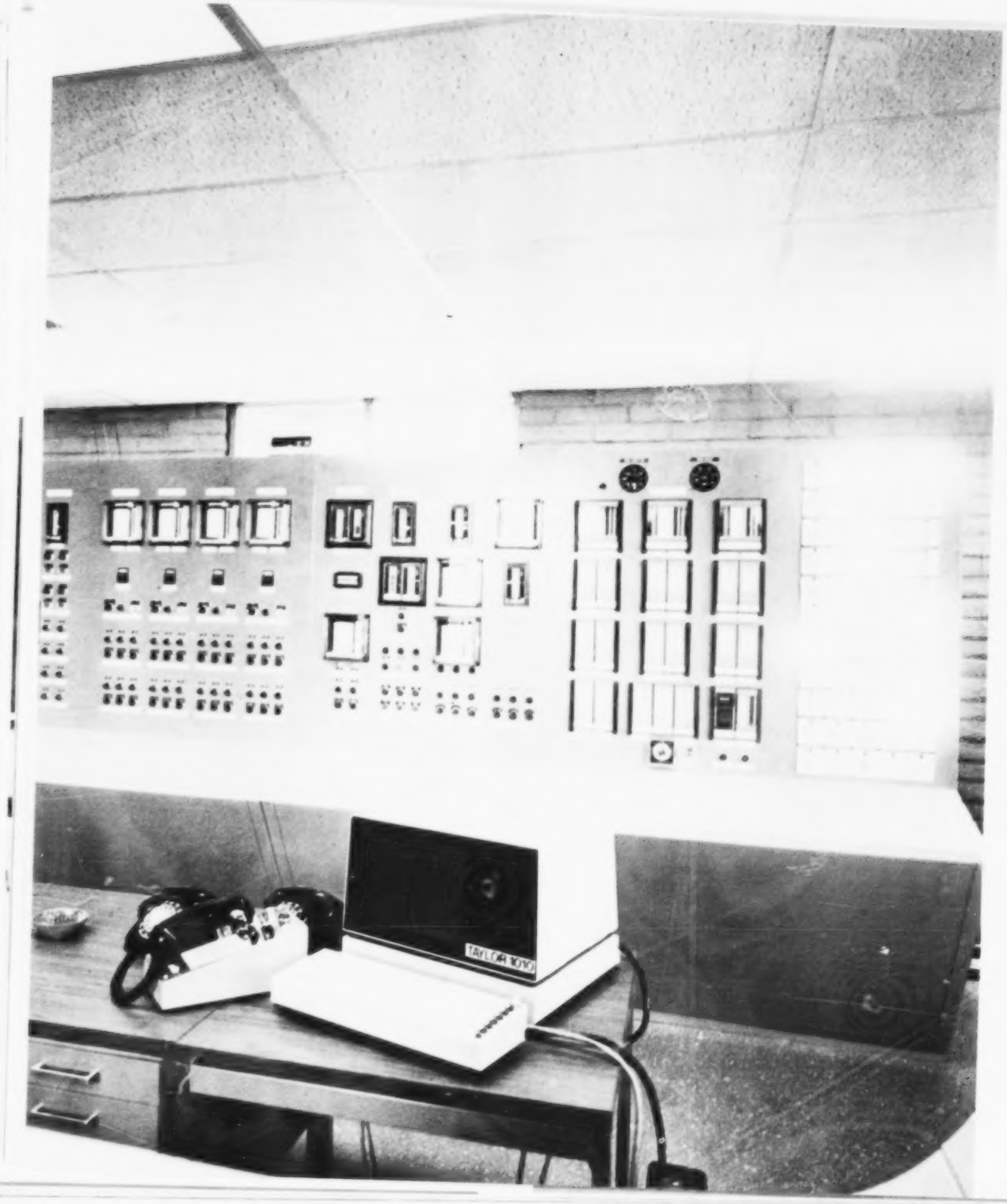
Costs of sludge incineration can range from $70-$160 per ton, depending on plant size, fuel costs, and sludge moisture. Costs for multiple-hearth and fluidized-bed systems are comparable, and a careful evaluation of local conditions is needed to determine if one system will have an economic advantage over the other. Each has its own operational advantages. The multiple-hearth furnace has the advantages of simpler maintenance and operation, but the disadvantages of requiring longer time periods for startup to avoid sudden changes in temperature that would damage the insulating bricks in the furnace. Also, the teeth on the internal rabble arms in the multiple hearth sometimes pose a maintenance problem. The fluidized-bed system has the advantage of more efficient fuel use. Because the sandbed retains heat even after operation has stopped, the incinerator is better suited for intermittent operation (one shift per day, for example). However, operation and maintenance are more complex. Some problems of scale accumulation on the sand have been reported. Both systems have demonstrated their ability to incinerate municipal sludges reliably without creating air pollution problems.

Energy requirements for incineration vary depending on furnace size and water content of the sludge. Electricity required for a multiple-hearth furnace may range from 50-200 kwh per ton of dry solids, while a fluidized bed furnace requires about 500 kwh per ton. Fuel required for incineration of a sludge at 16 percent solids, including combustion and startup fuel, is about 15 million Btu per ton. Combustion is self-sustaining for incineration of a sludge at 30 percent solids, and fuel requirements for startup are only about 0.5 million Btu per ton.

As an alternative to burning, organic sludge can be oxidized by a process called "wet air oxidation." This process is based on the principle that any substance capable of burning can be oxidized in the presence of liquid water at temperatures between 250°-700°F. The process can operate on difficult-to-dewater sludges where the solids are but a small percentage of the water streams, eliminating the need for dewatering. The sludge is passed through a grinder, and then into a reactor where high temperature (500° F or more) and pressure (1,000-1,700 psi) are applied. At this temperature, the high pressure is needed to keep the water from turning into steam. Air is injected also to speed oxidation. The oxidized solids and liquid can be separated by settling or by vacuum filtration or centrifuging. Wet air oxidation has the advantage of eliminating the dewatering step and minimizing air pollution potential, because oxidation takes place in water without producing exhaust gases containing flyash or dust. It has the disadvantage of creating a liquid very high in BOD, phosphorus, and nitrogen, which must be recycled through the wastewater treatment process, imposing a significant added treatment burden on the secondary process. Maintenance problems may be complex and the high-pressure/high-temperature system introduces some safety considerations.

AWT process sludges

As noted earlier, the coagulation-sedimentation process produces large volumes of chemical sludges. No other AWT process creates a significant sludge problem. Although spent activated carbon might be considered a waste solid, it is usually regenerated and reused and is a relatively dry solid that is easily handled. If lime is the coagulant used in coagulation-sedimentation, the sludge can be dewatered by the same techniques discussed earlier (vacuum filters, centrifuges, filter presses). It can then be passed through either a multiple-hearth or a fluidized-bed furnace in a process called "recalcining." This process drives off water and carbon dioxide, leaving a reusable form of lime behind. Recalcining reduces the volume of new lime that must be purchased, as well as the volume of sludge residual for disposal. The lime sludge has also been dewatered and buried in cases where recalcining economics were not favorable. The costs of lime recalcining are typically $40-$60 per ton of lime recovered. While these costs are, in most cases, about the same as buying new lime, an overall savings may result in that sludge disposal costs are reduced substantially by recycling most of the chemical sludge rather than disposing of it. Power required for lime recalcining ranges from 30-60 kwh per ton of solids and fuel requirements range from 5-10 million Btu per ton. Overall costs of dewatering chemical sludges and their ultimate disposal can add 10-25 cents per 1,000 gallons to the cost of wastewater treatment. If salts of iron or aluminum, such as alum or ferric chloride, are used as the coagulant, the chemicals cannot be recovered and reused for phosphorus removal. These sludges, then, are dewatered, with the same alternatives for disposal as the organic sludges from secondary treatment.

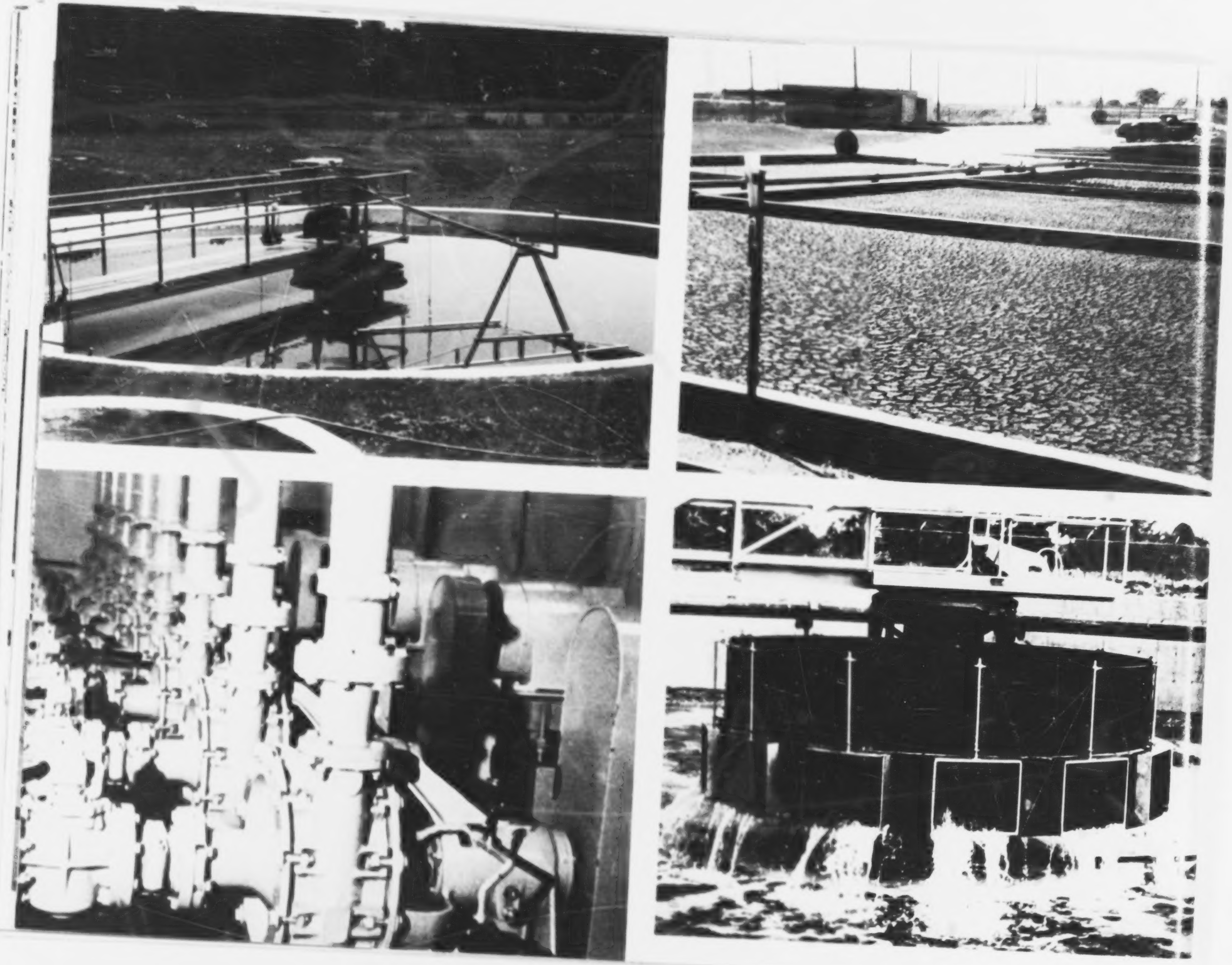


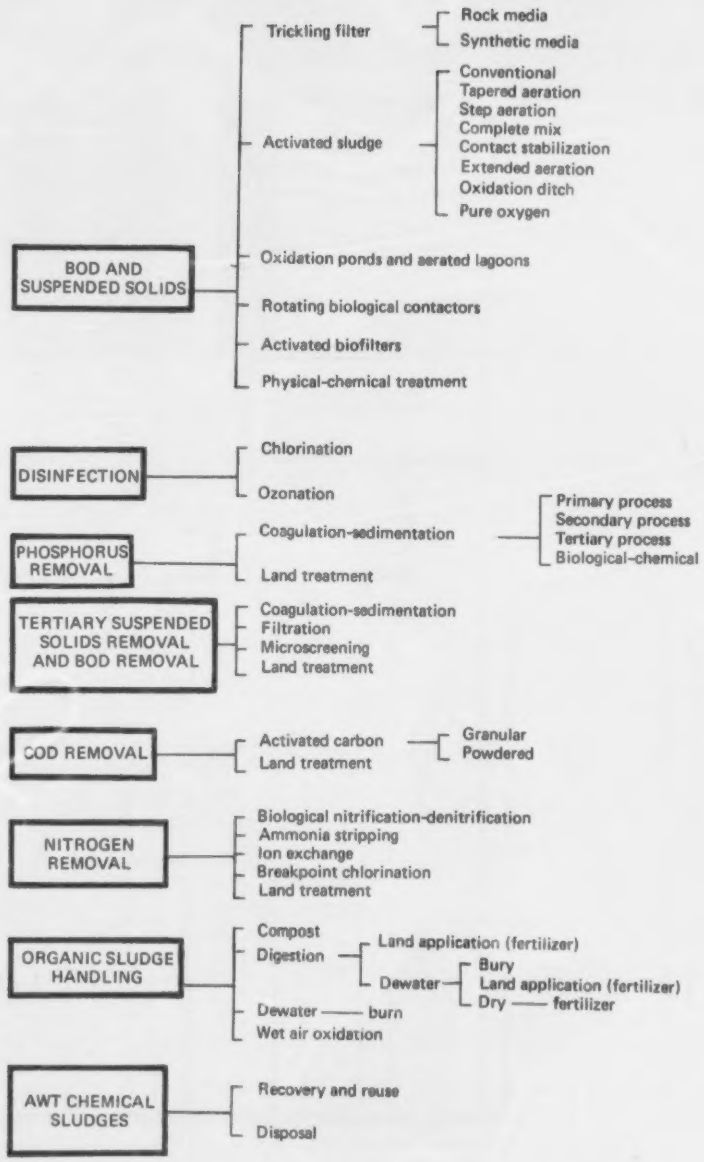
evaluating alternatives

It should be apparent that there are many alternatives available for wastewater treatment and for handling the sludges produced. There is no panacea; each wastewater treatment problem must be evaluated carefully in light of specific local conditions to determine the best solution. Among the factors that must be considered are

- *Nature of the raw wastes*—Current or future industrial wastes could have a significant effect on the capacity and performance of the treatment facility. Industrial pretreatment requirements may minimize these effects, but the process should be flexible enough to accommodate variations in pretreatment efficiency.
- *Effluent requirements*—The required effluent quality has an obvious, major impact on process selection.
- *Process reliability*—It is important that the processes selected provide the maximum degree of reliability.
- *Sludge production*—The ability to handle sludges produced by a candidate process in an economical and environmentally satisfactory manner is also a critical factor in process evaluation.
- *Air pollution*—A careful evaluation of the ultimate fate of pollutants removed from the wastewater must be made to insure that water pollution control has not been achieved at the expense of air pollution.

- *Resource consumption*—Wastewater treatment cannot be achieved without the expenditure of resources such as power and chemicals. It is obviously desirable to minimize the consumption of these resources, and the relative consumption by alternative processes is a factor for consideration.
- *Space requirements*—The relative space requirements of alternative processes are a factor in process selection.
- *Safety considerations*—Any potential hazards within the plant boundaries, or those which could affect the surrounding area as a result of plant malfunction or transport of materials to or from the plant, must be considered.
- *Costs*—It is obviously important to select a process that can achieve the project goals in the most cost-effective manner within the constraints imposed by the foregoing considerations.

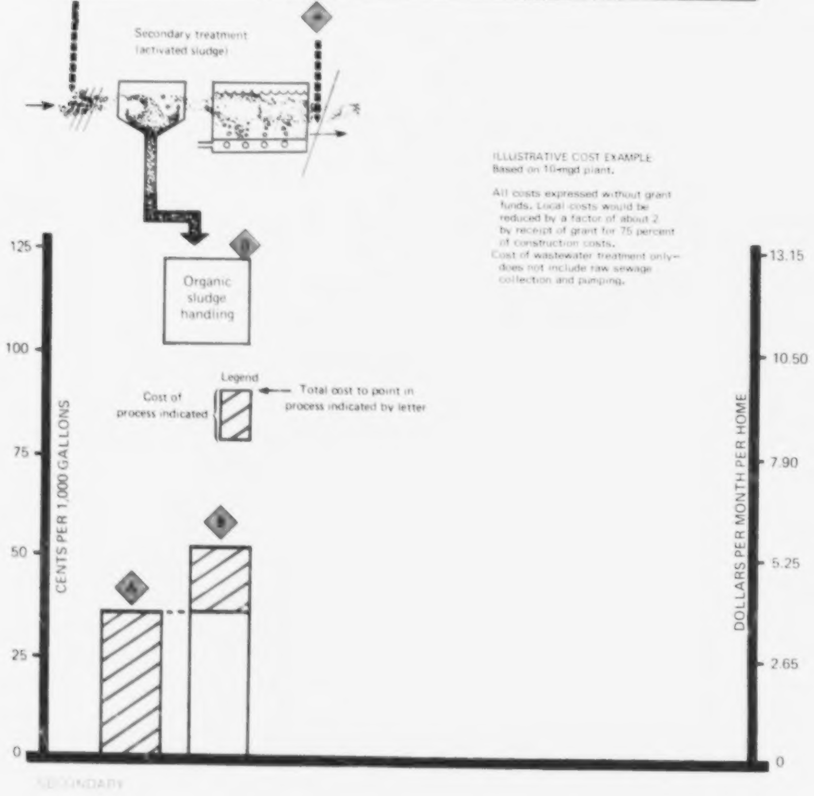



BOD AND SUSPENDED SOLIDS
Trickling filter
Rock media
Synthetic media
Activated sludge
Conventional
Tapered aeration
Step aeration
Complete mix
Contact stabilization
Extended aeration
Oxidation ditch
Pure oxygen
Oxidation ponds and aerated lagoons
Rotating biological contactors
Activated biofilters
Physical-chemical treatment
DISINFECTION
Chlorination
Ozonation
PHOSPHORUS REMOVAL
Coagulation-sedimentation
Primary process
Secondary process
Tertiary process
Biological-chemical
Land treatment
TERTIARY SUSPENDED SOLIDS REMOVAL AND BOD REMOVAL
Coagulation-sedimentation
Filtration
Microscreening
Land treatment
COD REMOVAL
Activated carbon
Granular
Powdered
Land treatment
NITROGEN REMOVAL
Biological nitrification-denitrification
Ammonia stripping
Ion exchange
Breakpoint chlorination
Land treatment
ORGANIC SLUDGE HANDLING
Compost
Digestion
Land application (fertilizer)
Dewater
Bury
Land application (fertilizer)
Dry — fertilizer
Dewater — burn
Wet air oxidation
AWT CHEMICAL SLUDGES
Recovery and reuse
Disposal

SUMMARY OF AVAILABLE ALTERNATIVES RELATIVE TO REQUIREMENTS FOR POLLUTANT REMOVAL

The best alternative system for pollutant removal must be selected based on a case-by-case study of efficiency and actual costs. Illustrative cost ranges have been presented throughout this report. To illustrate the costs associated with each increment of quality improvement, the next few pages present an example of how processes may be added to a conventional secondary plant to achieve removal of pollutants such as phosphorus, nitrogen, and COD and further removal of BOD and suspended solids, and the resulting costs. Of course, there are many possible combinations and process sequences that could be used. For example, nitrogen removal could occur immediately after the secondary process rather than at the point shown. The overall costs would not be affected, however. The example shows how available processes can be added step by step to an existing system in modular increments as needed if treatment standards continue to become more rigid. Current EPA research efforts are aimed at finding more economical processes to achieve high levels of treatment. However, proven treatment technology is available today to eliminate municipal wastewaters as a significant source of pollution and to convert them to a valuable resource if water reuse is needed in an area.

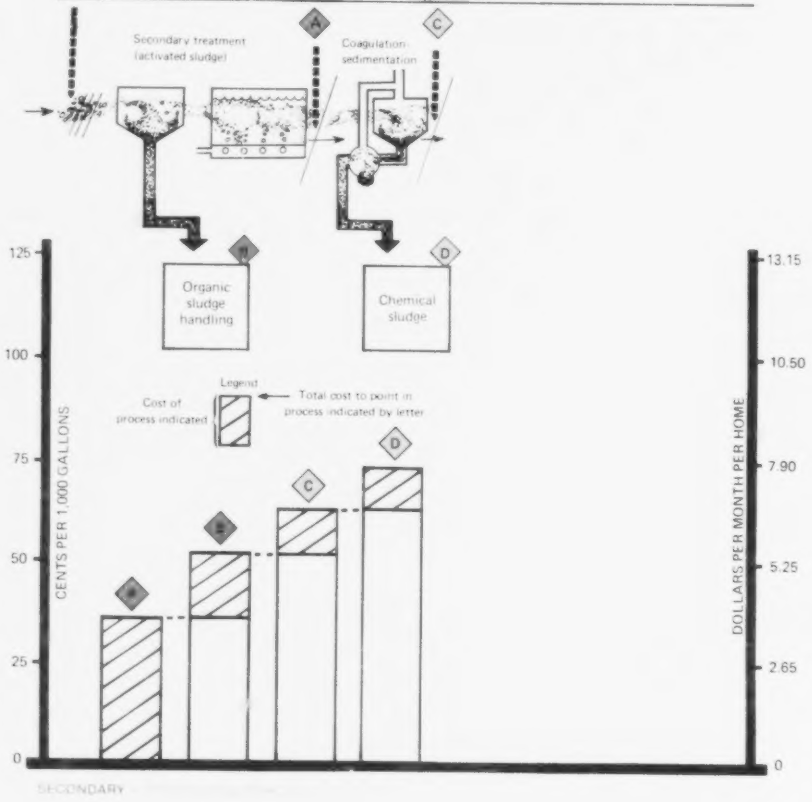
Raw sewage		Effluent quality
200	BOD: mg/l % removal	20 90
400	COD: mg/l % removal	80 80
200	Suspended solids: mg/l % removal	20 90
20	Nitrogen: mg/l % removal	18 10
10	Phosphorus: mg/l % removal	9 10

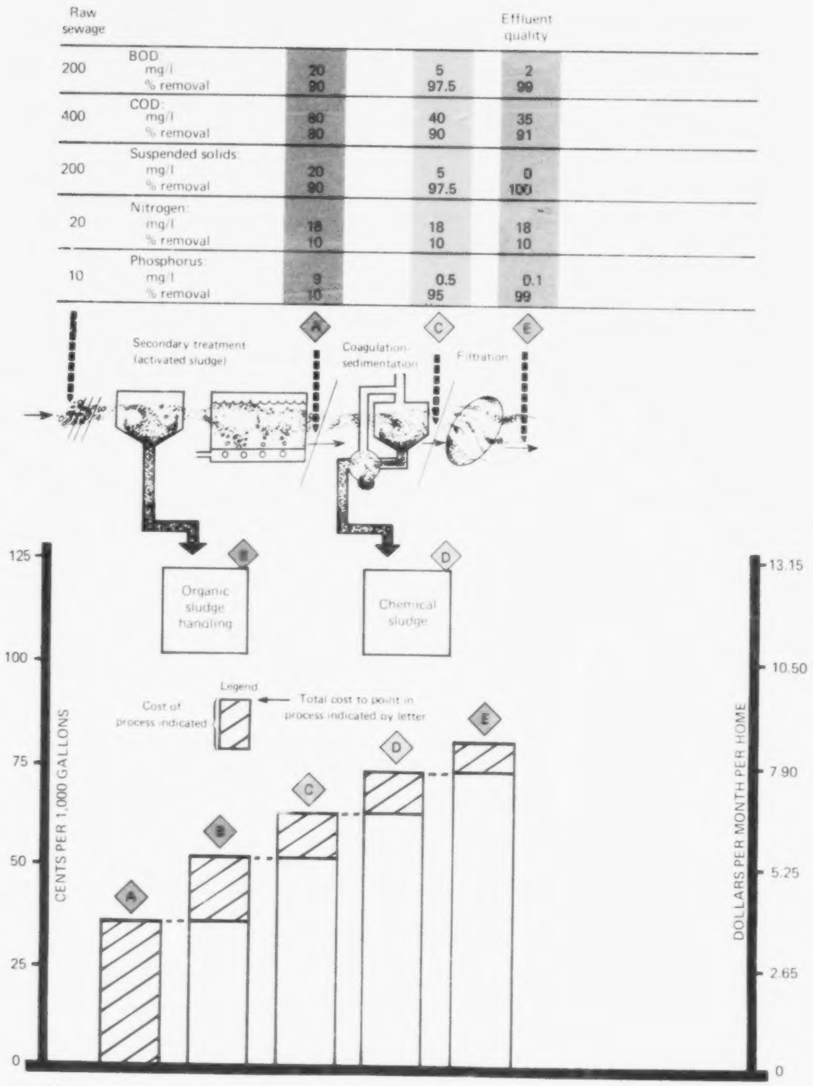


ILLUSTRATIVE COST EXAMPLE
Based on 10-mgd plant.

All costs expressed without grant funds. Local costs would be reduced by a factor of about 2 by receipt of grant for 75 percent of construction costs.
Cost of wastewater treatment only—does not include raw sewage collection and pumping.

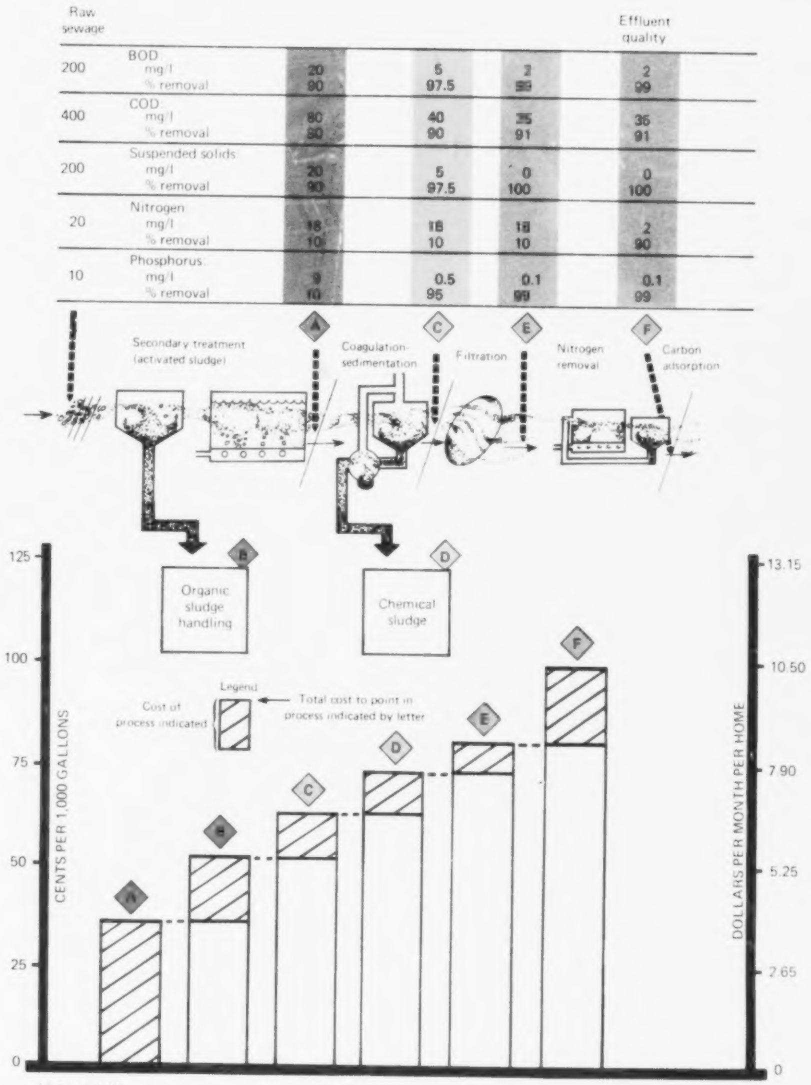
Raw sewage			Effluent quality
200	BOD: mg/l % removal	20 90	5 97.5
400	COD: mg/l % removal	80 80	40 90
200	Suspended solids: mg/l % removal	20 90	5 97.5
20	Nitrogen: mg/l % removal	18 10	18 10
10	Phosphorus: mg/l % removal	9 10	0.5 95





Raw sewage		A	C	E Effluent quality
200	BOD: mg/l % removal	20 90	5 97.5	2 99
400	COD: mg/l % removal	80 80	40 90	35 91
200	Suspended solids: mg/l % removal	20 90	5 97.5	0 100
20	Nitrogen: mg/l % removal	18 10	18 10	18 10
10	Phosphorus: mg/l % removal	9 10	0.5 95	0.1 99

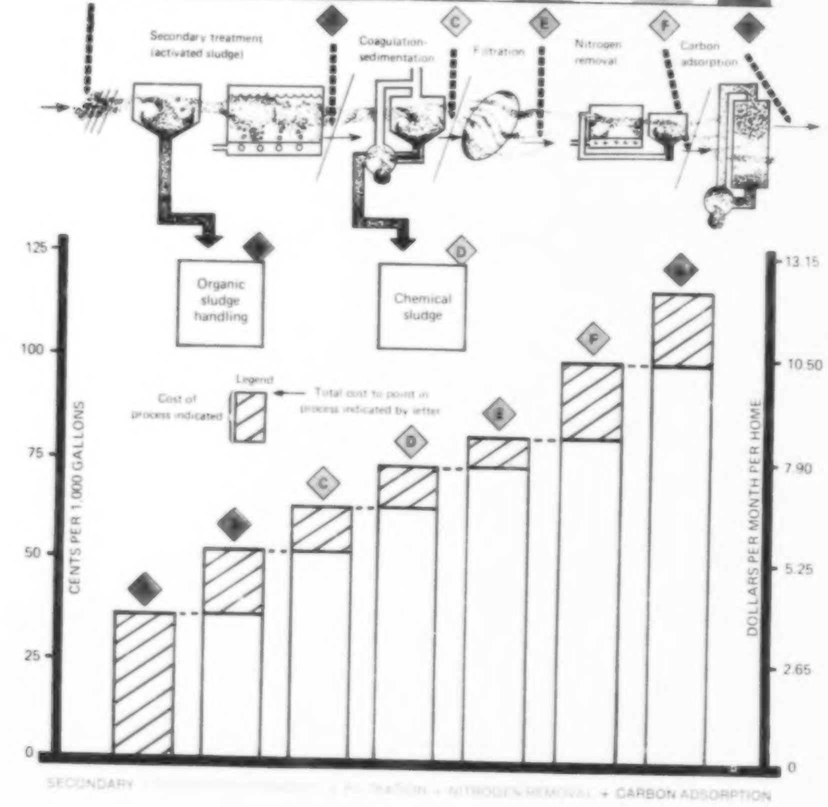
SECONDARY



Raw sewage		A	C	E	F Effluent quality
200	BOD: mg/l % removal	20 90	5 97.5	2 99	2 99
400	COD: mg/l % removal	80 80	40 90	35 91	35 91
200	Suspended solids: mg/l % removal	20 90	5 97.5	0 100	0 100
20	Nitrogen: mg/l % removal	18 10	18 10	18 10	2 90
10	Phosphorus: mg/l % removal	9 10	0.5 95	0.1 99	0.1 99

SECONDARY FILTRATION — NITROGEN REMOVAL

Raw sewage						Effluent quality
200	BOD: mg/l % removal	[illegible]	5 97.5	2 99	2 99	[illegible]
400	COD: mg/l % removal	[illegible]	40 90	36 91	36 91	[illegible]
200	Suspended solids: mg/l % removal	[illegible]	5 97.5	0 100	0 100	[illegible]
20	Nitrogen: mg/l % removal	18 10	18 10	18 10	2 90	[illegible]
10	Phosphorus: mg/l % removal	[illegible]	0.5 95	0.1 99	0.1 99	[illegible]



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